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MECHANICAL ENGINEERING

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ME 4182
MECHANICAL DESIGN ENGINEERING

NASA / UNIVERSITY
ADVANCED DESIGN PROGRAM

SKITTER / IMPLEMENT MECHANICAL INTERFACE

JUNE 1988

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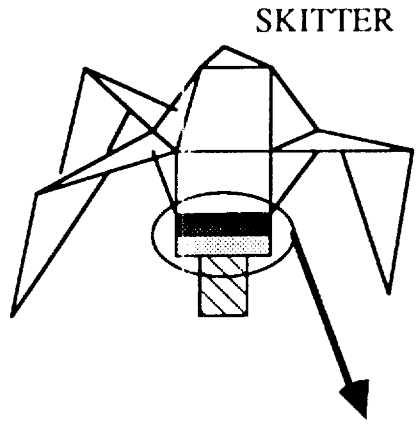
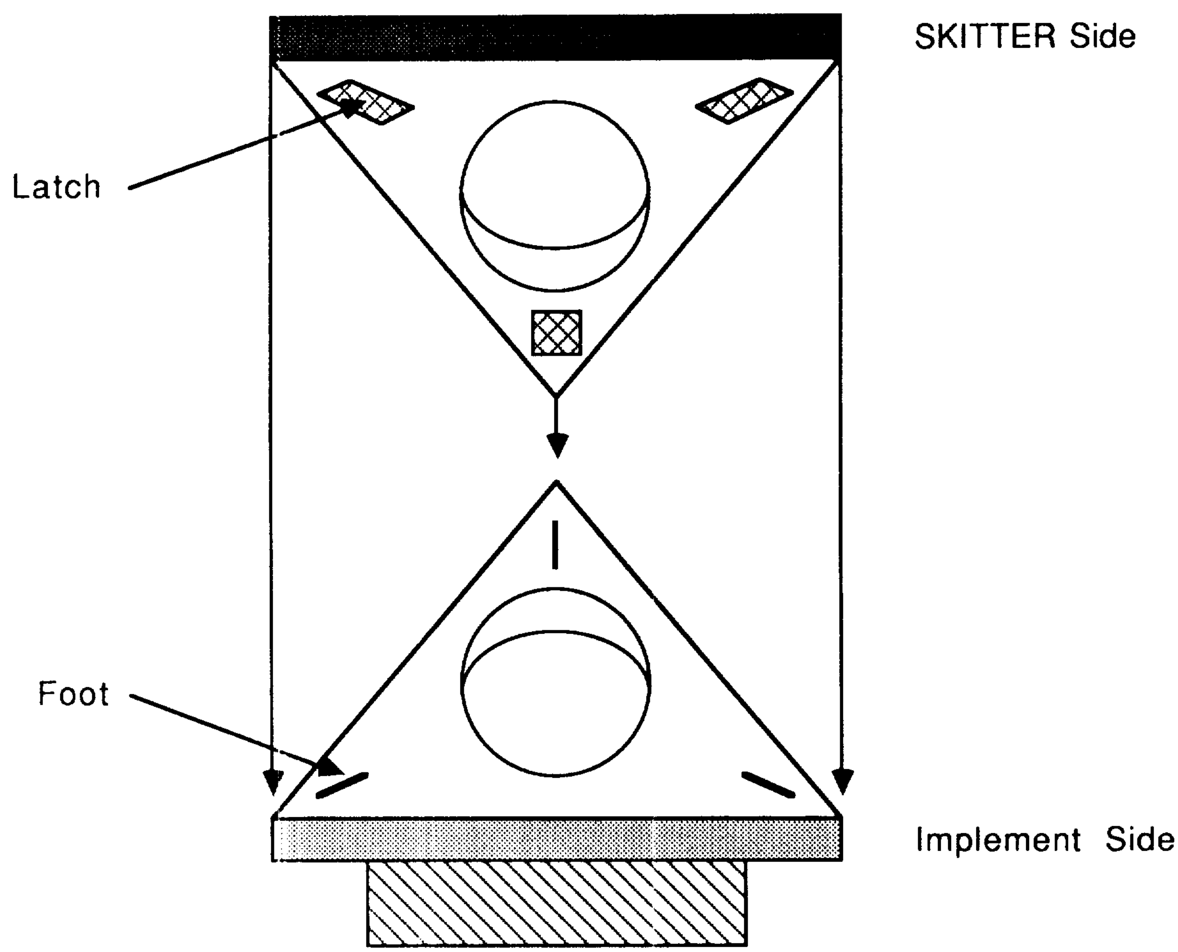
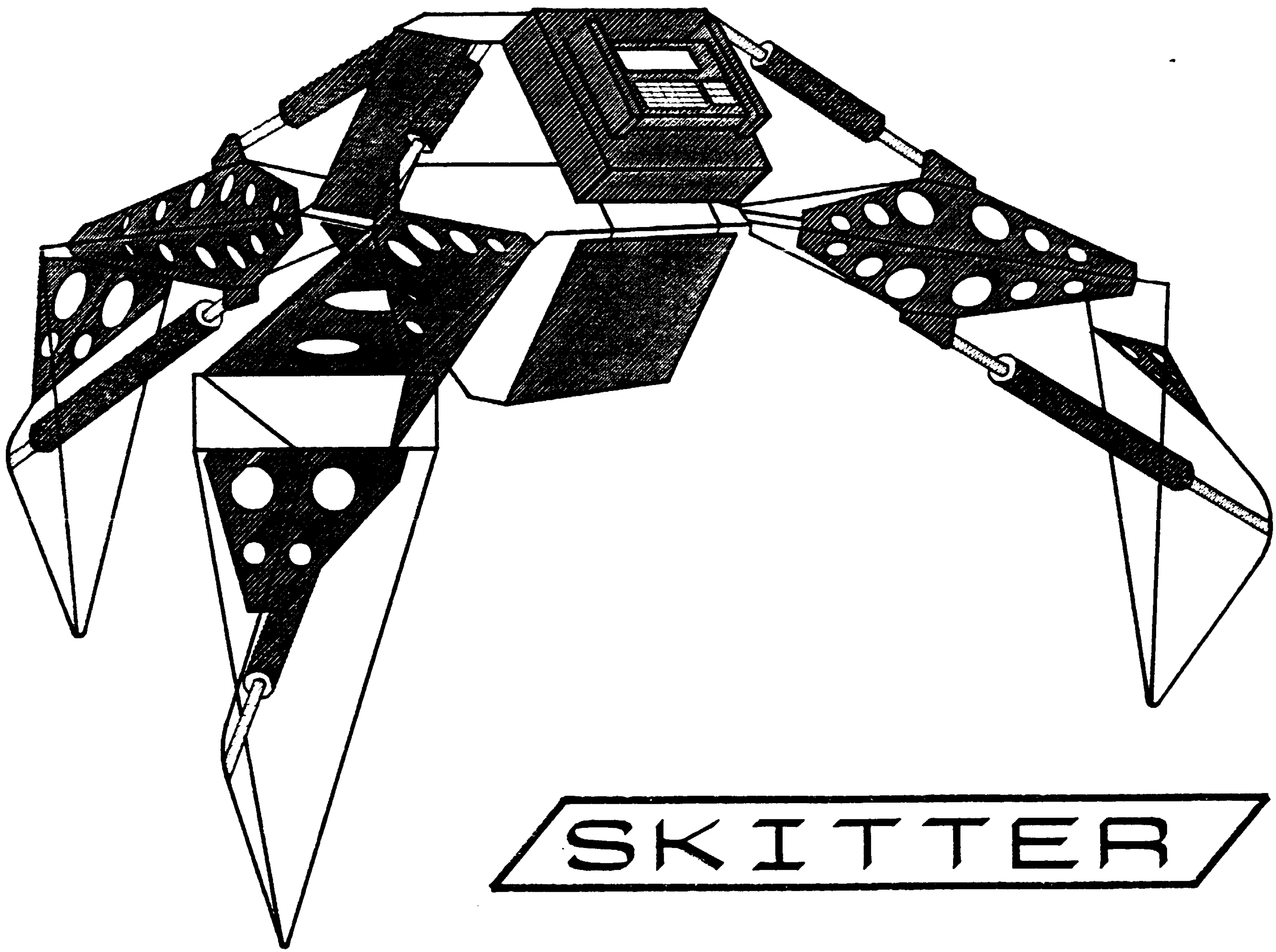






SKITTER

1. ABSTRACT

The objective of this project was to design a mechanical interface for SKITTER. This mechanical latching interface will allow SKITTER to use a series of implements such as drills, cranes, etc, and perform different tasks on the moon. The design emphasizes versatility and detachability. That is, the interface design is the same for all implements, and connection and detachment is simple. After consideration of many alternatives, a system of three identical latches at each of the three interface points was chosen. The latching mechanism satisfies the design constraints because it facilitates connection and detachment. Also, the moving parts are protected from the dusty environment by housing plates.

2. OVERVIEW OF SKITTER

S.K.I.T.T.E.R. (Spacial Kinematic Inertial Translatory Tripod Extremity Robot) is a three-legged transport vehicle designed to perform under the unique environment of the moon. In order to achieve the simplest mechanical system possible, design engineers considered the most simple statically stable device, the tripod. Three legs, arranged at 120 degree intervals, and a central platform, make up the structure. A femur link and tibia, terminating as foot, comprise each leg.

Electromechanical actuators serve as the hip and knee joints. The hip joint alters the angular position of the femur relative to the platform. The knee joint changes tibia position relative to the femur.

Operation involves a closed-loop velocity feedback system and a master/slave relationship between controlling devices. Each slave, a dedicated microprocessor, calculates link velocity based on input from its respective position sensor. Results are compared to the prescribed velocity for that particular position while the error signal, conditioned by the gain, governs actuator motion.

The master, a remote human operator and/or on-board computer, coordinates slave action to achieve a variety of platform positions. Actuating a single leg, for example, forces the platform to lean from its equilibrium position - maneuver for zeroing in on targets. The same procedure, applied to the other legs, lowers the platform close to, or with enough iterations, directly onto, an implement .

To traverse distances, move radially, or rotate about a single point, the mobile platform makes use of the moon's low gravitational force. Each leg pushes off from the surface, changes position, and falls back into contact with the surface at a new point.

The three-legged platform offers several advantages over the lunar vehicle concepts, according to its designers, Jim Brazell, Brice MacLaren, and Gary McMurray of The Georgia Institute of Technology. SKITTER which can be used as a transportation or carrying cargo device is very versatile. [1]

1. David J. Bak, "Three legs make mobile platform " , Design News, February 15, 1988, page 136.

3. PROBLEM STATEMENT

A. BACKGROUND AND PERFORMANCE OBJECTIVES

SKITTER will use a series of implements to perform different tasks on the moon. Some of these implements are cranes, robotic arms, augers, drills, etc. Interchangeability is the prime consideration in the use of these implements by SKITTER. Therefore, the implements are detachable, and the interface designed must be the same for all implements.

B. GEOPHYSICAL CONSTRAINTS

Due to the moon's geophysical characteristics (dusty environment, drastic temperature range, lack of atmosphere, and a gravitational force which is 1/6 that of the earth), a mechanical interface that will perform under theses conditions is an imperative need.

i. Gravity

Although the diameter of the moon is about one-quarter that of the earth, the moon weighs only about one-eightieth as much as the earth. The force of gravity at the moon's surface is only one-sixth that of the earth. Therefore, an implement weighing approximately 350 pounds on the earth weighs only about 60 pounds on the moon. This fact most be considered when designing a mechanical interface.

ii. Atmosphere

The moon has no atmosphere because it's gravity is too weak to hold an atmosphere like the earth's. If relatively light gases like oxygen, nitrogen, and water vapor were ever present on the moon, their molecules must have escaped into space long ago. The gravity of the moon is strong enough to hold back heavier atoms like argon and radon, but there are not enough of these elements present to make any tangible atmosphere. Due to this lack of atmosphere, liquids evaporate on the moon. This creates a constraint during the design process when lubricants are a concern. Also, since there is no humidity, the moon's soil is dry and very dusty.

iii. Radiation

The lack of atmosphere on the moon means that, unlike the earth, the surface of the moon has no protection from continuous bombardment by tiny meteorites and from scorching by lethal X-rays, gamma rays, and cosmic rays that originate from the sun and the rest of the universe. This fact is an important consideration during the materials selection of the design process. Most metals are not very susceptible to ultra-violet radiation. However, polymers are sensitive and should be shielded.

iv. Temperature

As the moon moves around the earth, it turns so slowly that it always keeps the same side facing toward the earth. The moon thus rotates once on its axis in the same time that it makes one trip around the earth. To keep one face turned always to the earth, the moon must turn its back on the sun during half its orbit.

As a result of these motions, the 29 and 1/2 - day month is divided on the moon into a lunar "day" and a lunar "night," each about two weeks long. Because the moon has no insulating atmosphere, the "daytime" temperature in direct sunlight is approximately 134° C. (270° F.), well above the boiling point of water. During the lunar "night," the temperature drops suddenly (200° C per minute) to about -170° C. (-270° F.), much colder than the freezing point of carbon dioxide ("dry ice").

C. MECHANICAL CONSTRAINTS

In addition to the geophysical constraints, there are mechanical constraints introduced by the geometrical shape of the connecting region on SKITTER, the locomotion of SKITTER, and the desirable weight of the implements. The shape of the connecting region on SKITTER is that of an equilateral triangle with a circular hole in its center. The sides of the triangle are 7 feet in length and the inscribed circle is approximately 4 feet in diameter.

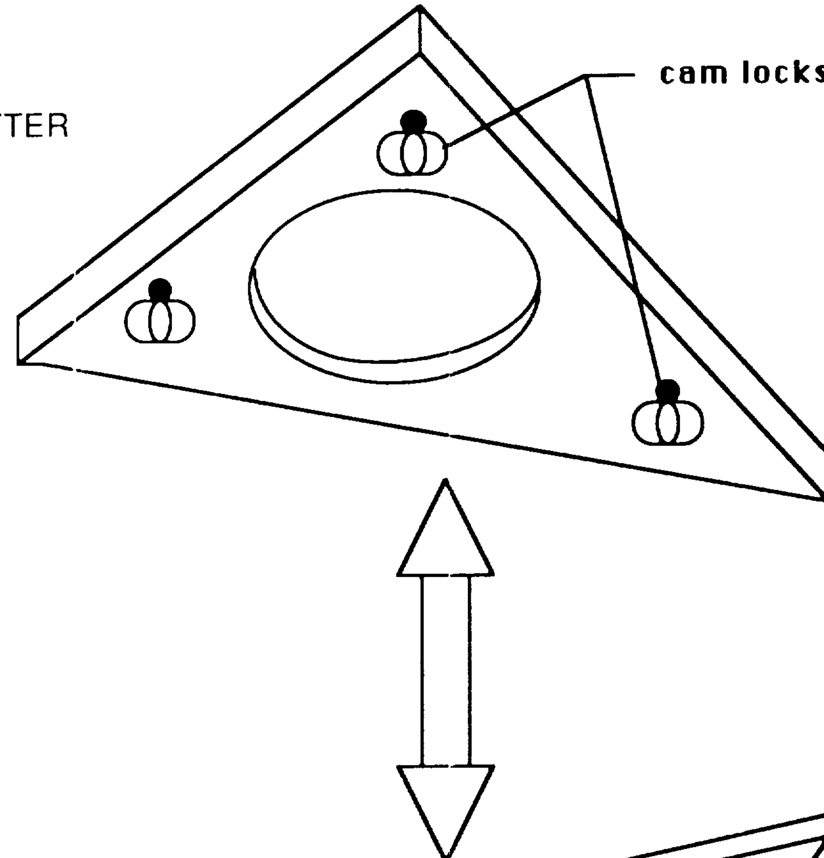
SKITTER's locomotion resembles a modified 'crutch walk' characteristic of a three legged transport vehicle.

4. DESCRIPTION

The mechanical latching interface unit for the SKITTER transport vehicle consists of three rotating cam locks located on the SKITTER section (Figure 1), and three latch rods located on the implement section (Figure 2). The latching unit offers several advantages such as quick connection and quick detachment if any mechanical failure occurs. The dimensions of the latching unit are limited by the geometrical constrains mentioned in the problem statement. The selection of materials is also limited by the geophysical characteristics of the moon. However, for consistency on the strength to weight ratio of SKITTER and the mechanical interface the same material should be used on both. An appropriate choice would be an aluminum alloy such as 6061-T6 or any other aluminum of the 6000 series. Each lock on the unit located on SKITTER comprises of two rotating cams, a locking pin loaded with a spring, high tolerance dry bearings, guides, and an actuator.

FIGURE 1.

Unit on SKITTER



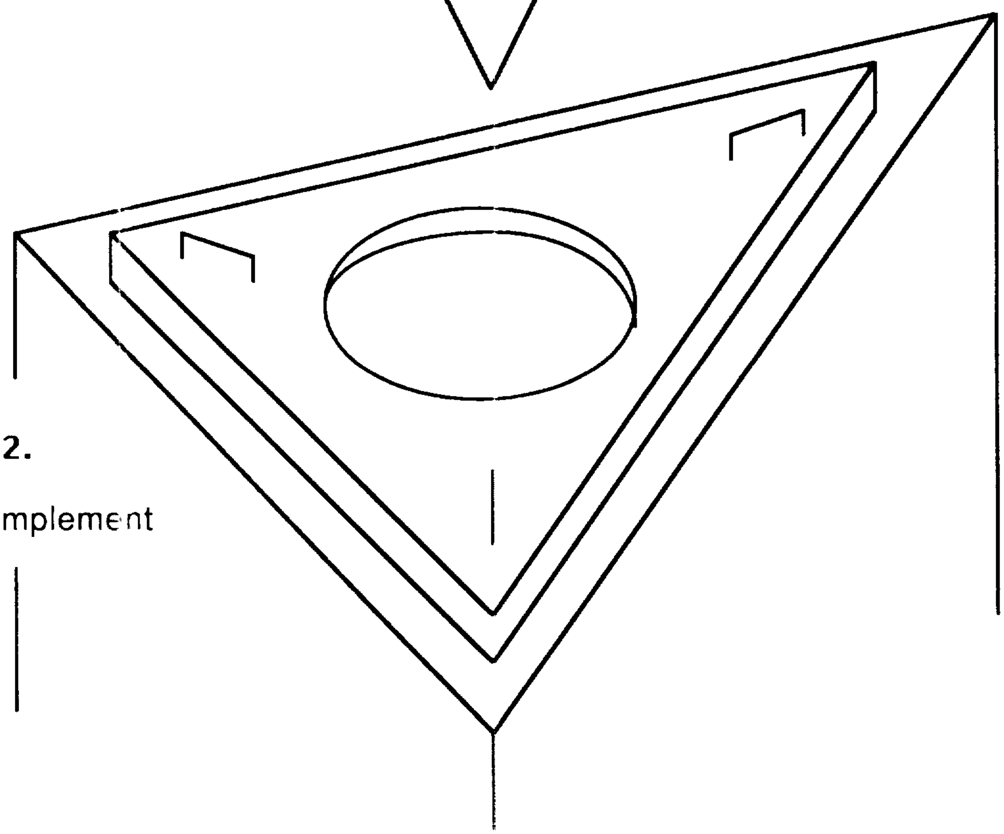


FIGURE 2.

Unit on Implement

5. ANALYSIS

A. INTRODUCTION

This section of the report includes a short, more detailed description of each of the components of the mechanical latching interface unit. It also shows the design techniques for the components. After the initial conceptualization, the design is determined primarily by operation and force requirements. A final tabulation of weights appears in the Appendix. Also, for actual calculations see the Appendix.

B. MATERIALS / FABRICATION

Desired properties:

- Low coefficient of thermal expansion.
- Resistance to intense U.V. radiation.
- Little variation of properties within a temperature range from -270° F to 270° F.
- High strength to weight ratio.
- Resistance to sliding wear (Actuator and latch mechanism).
- Resistance to cold welding.
- Resistance to brittle fracture at low temperatures.
- Ease of machineability during manufacturing of implements.

Due to the geophysical constraints inherent to the lunar surface, it is necessary to select a material which displays good strength characteristics and resistance to corrosion and environmental attach. Additionally, the material should not be adversely affected by the extremes in temperature which are encountered on the lunar surface. Also, since launch costs are considerable, a high strength to weight ratio is important.

It was found that an Aluminum alloy (6061-T6) has many of the physical properties that are tolerable to the lunar environment. This aluminum alloy(6061-T6) consists of the following components: 1% Mg, 0.6% Si, 0.25% Cu,).20% Cr, the metal is also solution heat treated and artificially aged. The density of the alloy is 0.098 lb/in3 and has a tensile strength of 45 ksi and an ultimate yield strength of 39 ksi. Thus, through the alloying process, aluminum can obtain strengths twice that of mild steel. This alloy has one of the highest strength to weight ratio and can be compared to superalloy steels and titanium. Al 6061-T6 also has a low coefficient of thermal expansion (B=0.005 in/in) for the range -250 F to 210 F. and thus will retain its shape over a wide range of temperatures. Aluminum alloys also exhibit excellent cryogenic properties and actually become tougher at lower temperatures, whereas most steels become brittle at cryogenic temperatures. Aluminum 6061 can be worked using a variety of methods such as machining, extrusion, casting etc. It may also be welded.

Although aluminum is a highly chemically active metal, it possesses an excellent resistance to corrosion. This resistance is due to a natural forming film that bonds to the surface of the material. This film is transparent and thus does not detract from the reflectivity of the aluminum. This reflectivity can be useful in maintaining a constant temperature gradient across the interface and latches.

Material properties for Aluminum 6061-T6 are given in section C of the Appendix.

C. ALTERNATIVE MATERIALS

Aluminum 6061-T6 is in widespread use for lunar applications due to its combination of high strength at elevated temperatures, low weight, and resistance to deterioration by the moon's atmosphere. Presently, other materials are being developed which may yield better overall properties. Aluminum - lithium is a promising alloy that has been gaining much attention. Similar in density to the 6061 alloy, it has increased strength and is stable up to 700° F. Parts may be forged from this alloy using power metallurgy, a relatively new technology which uses pressure to form parts in a heated mold.

Aluminum has also been ALLOYED with iron, and vanadium to yield higher strengths. For example, aluminum 2090-T8 has a lower density than many other alloys, has a higher elastic modulus, and is highly resistant to corrosion and fatigue. Aluminum 8090 which is a copper, lithium, and magnesium alloy, also displays many promising applications for moon use.

Aluminum lithium alloys in the T6 configuration may be plastically formed into shapes, using a process similar to vacuum forming. A new class of alloys, alumicides, has been gaining much recent attention due to its high strength and good high temperature properties. Beryllium alloys typically have a density of two-thirds that of aluminum alloys. Their elastic modulus is high, close to four times that of aluminum but, they are prone to surface cracks, corrosion, brittleness, and are toxic to handle when processing. They also typically have low impact strength. Magnesium alloys are light, but have lower strengths than aluminum. They also have problems with elasticity and machining. Beryllium copper alloys show display some desirable qualities. Titanium alloys are very tolerant of high temperatures and have an elastic modulus of 1.5 times that of aluminum. These alloys, with many useful characteristics, are difficult to work with, brittle, and very expensive.

D. FEET

The foot is the name given to the rod which is mounted on the implement to be grasped (Figure 3). SKITTER uses these rods (three of them) to hold on to the implement. The foot consists of a 1" diameter rod which is 4.5" long. The last 0.25" of each end is milled to a hexagonal cross section with a hole to accept a 1/4 x 20 bolt at each end. The rod is designed for a 1,000 lb static load (applied at the center causing bending) with a 3.4 factor of safety for dynamic considerations.

The rod is attached to the implement with 1/4" triangular plate mount, surrounded by a conical shell (Figure 3). The side plates have a hexagon shaped hole to accept the rod ends. Two A574 1/4 x 20 socket head cap screws 1 1/4" long are used to hold the rod onto the plate along with lock washers. Overall, the plates are high enough to keep to rod at a sufficient distance from implement to allow room for latching.

The end plates are also triangular and 1/4" thick, one for each end, to give strength in a direction parallel to the rod's axis. The plates are all welded to each other with 3/16" fillets all around.

The feet are mounted to the implement in a radial configuration (Figure 4). This is to prevent motion in all horizontal directions, aside from deflection, while the implement is being used. Such configuration also allows attachment even when the feet are slightly out of line due to thermal expansion or contraction of SKITTER or the implement. Such changes in position are of the order of 1 cm.

E. ROTATING CAMS

The shape and size of the cams are determined by forces as well as operational considerations. The bottom of the cams is shaped to cause them to open when they are pushed down on the rod. The tops are shaped to cause them to close when the rod is seated. The inner circular shape is slightly larger than the rod diameter of the foot. The outer shape and thickness of the cams are determined by the forces that the cams must support. (Figure 5).

F. CAMSHAFTS

The main shafts are rigidly connected to the cams by fillet welds. The shafts are sized at 3/4" diameter $\pm$ 0.005" to take the 1,500 in-lb of torque using a shear yield strength as one half of the tensile yield strength. Each shaft will hold 2,900 lbs of concentrated load in bending between the housing plates. The total length of the shafts is 3 1/4" to extend through the entire latch (Figure 6).

G. ROLLERS

The rollers are dry, straight roller bearings and are sealed. They have a 1/4" I.D. , 3/4" O.D., and are 1/2" wide. They are mounted on the roller shafts. They are forced against the locking pin while the latch is closed in order to keep the cams from opening. Their function is to prevent excessive sliding friction during latching and unlatching (Figures 6 and 7).

i. Roller Mounts

The rollers are to be positioned with their centers of rotation offset 3/4" from that of the camshafts. To accomplish this, two mounts per roller are attached to the camshafts (Figure 6). They are designed to hold 500 lbs of bending force each, applied at the roller axis. They are welded to the cam shafts all around with 3/16" fillet. They are sized to give 1/8" clearance between the camshafts and the bottom of the rollers. The top of the mounts are tapered to allow the roller surfaces to extend beyond them and contact the locking pin.

ii. Roller Shafts

The roller shafts extend between the roller mounts and are rigidly connected to them(Figure 8). They are sized at 1/4" ± 0.005" diameter with a 500 lb capacity in distributed bending load.

H. LOCKING PIN

The locking pin is a straight piece of metal which moves vertically between the rollers to prevent them from moving. It measures 1 1/4" x 7/8" 1 1/2" long (Figure 9). The bottom end is rounded to allow easy movement between the rollers. The front and back sides are slotted to restrict the motion vertically. The slots are 1/4" wide and 1/8" deep ± 0.005". The load on the pin is purely compressive. Two holes are drilled through the top of the pin to allow the connection of springs. These holes are 1/4" in diameter and 1.3" deep.

I. HOUSING PLATES

i. Front and Back.

The front and back of the housing plates are designed to act as guides for the foot, as well as, protection for the latch components (Figure 10).

ii. Top and Strengthening Wedges.

The top is used to mount latch to SKITTER, and it has a hole in the middle for the actuator. Wedges add strength to the housing structure.

J. ACTUATOR

The actuator is an electric solenoid producing linear motion in both directions over a length of 1" with a force of 40 lb. The position of the actuator is above the locking pin. It is totally enclosed within the SKITTER frame (See section D of the Appendix for information on the actuator).

K. SPRINGS

One set of springs is used to hold the locking pin in place. This set comprises of two compression springs with a spring constant of 5 lb/in. They have a free length of 2.6" an a compressed length of 1.25". They have an outside diameter of 0.2" and fit inside two 1/4" holes in the locking pin. Sleeves which are slightly greater in diameter but able to fit through the holes are used to prevent the springs from buckling.

L. FAILURE

Failure of the actuator on a latch will not allow the implement to be released. Therefore some sort of back-up system should be implemented. An alternative would be to install an explosive charge that will be detonated to "blow" the locking pin on the failed latch. Either damage to the SKITTER or implement side will allow disengagement. Failure of one or two of the latches to close will render the SKITTER side of the interface inoperable. The interface will not support the loading and damage will occur.

M. POWER REQUIREMENTS

The mechanical interface for SKITTER has been designed assuming a 24 volts D.C. power supply. This assumption is based on the possibility of using the available solar radiation. Also, new technology in electrochemical fuel cells may be perfected in the near future. Electrical power is easily obtained, and is not affected by extreme temperature variations or lack of atmosphere.

6. OPERATION

The mechanical interface is designed to allow SKITTER to grasp, hold, release, or drop its implements under a variety of conditions. The most common scenario is with the implement sitting in its storage rack in a horizontal position. When ready to use the implement, SKITTER walks to the rack, centers itself over the implement, and them lowers onto it. Because of the presence of built-in guides, SKITTER can miss the rods by $\pm$ 1" in the transverse direction, and $\pm$ 1 1/2" in the longitudinal direction with respect to each rod. Once the rods are guided into place, their own motion serves to first open the cams, and then close the cams. This action is possible due to the shape of the cams. When the rods are fully engaged, the locking pin is pushed into the space between the rollers to keep the cams closed.

SKITTER could also grasp the implement even if it were not in a horizontal rack. The latches work in any orientation. Their latching capabilities are only limited by SKITTER's range of motion.

In the case of releasing an implement, it can either be taken back to the rack and set down, or dropped at the working site for whatever reason. The unlatching process is the same for both cases. The locking pin is pulled out from between the rollers by the actuator. The weight of the implement or the movement of SKITTER then causes the cams to open due to the force of the rods on them.

While the latch is not in use, the normal position is locked with the pin engaged since it is spring loaded. Therefore, the pin must be disengaged before latching proceeds.

7. CONCLUSIONS AND RECOMMENDATIONS

This design project meets all requirements set forth in the original problem statement. Implements can be easily interchanged since they all have the same passive configuration. The mechanical components involved are strong enough for the assumed forces during SKITTER's operation on the moon. No liquid lubricants or pneumatic actuators are used, so the high vacuum conditions of the moon do not create problems. Also, the materials involved will withstand the radiation and temperature extremes found on the moon.

However, some constraints are only met to a degree. The two most important are dirt tolerance and weight. Dirt tolerance was considered and addressed by first minimizing holes and corners to avoid dirt settlement, and second, by enclosing the latching mechanism in a sealed housing. To get a practical idea of the performance of the design in a dusty environment, a prototype interface should be tested in a simulated lunar environment.

Weight was minimized by keeping the latch as compact as possible and by using a high strength to weight ratio aluminum alloy. Further optimization of the configuration and sizing is also recommended.

8. ACKNOWLEDGMENTS

The production of this project was made possible with the assistance of the following:

Prof. James W. Brazell - School of Mechanical Engineering
Georgia Tech.

Brice MacLaren - Graduate Student, Georgia Tech.

Gary McMurray - Graduate Student, Georgia Tech.

Harry Vaughan - Shop Assistant, School of Mechanical Engineering, Georgia Tech.

Virgil McConnell - Shop Assistant, School of Mechanical Engineering, Georgia Tech.

Butch Cabe - Shop Assistant, School of Mechanical Engineering, Georgia Tech.

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10. FIGURES

11. APPENDIX

A1. Progress Reports.

A2. Figures.

B1. Design Matrix.

B2. Set of drawings / sketches for alternative designs.

C1. Sy vs. T plot for Al 6061-T6.

C2. Aluminum 6061-T6 properties.

D. Actuator Information.

E1. Weights Table.

E2. Calculations.

APPENDIX A1.
PROGRESS REPORTS

TO: Mr. J. W. Brazell
FROM: Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
SUBJECT: Progress report for week of April 11, 1988.

Each group member submitted one idea each for the interface and crane hook. In addition the following was accomplished:

Will Cash - Helped develop problem statement.

Alan Cone - Initialized search for materials.

Frank Garolera - Helped define design constraints.

David German - Aided in search for existing designs.

Dave Lindabury - Started considering practical use of ideas.

Cleve Luckado - Helped in consideration of ideas.

Craig Murphey - Helped develop problem statement.

Bryan Rowell - Aided in defining constraints.

Brad Wilkinson - Helped in search for materials.

TO: Mr. J. W. Brazell
FROM: Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
SUBJECT: Progress report for week of April 18, 1988.

A general design for both the interface and crane hook were decided upon. In addition the following was accomplished:

Will Cash - Developed mechanical drawing of proposed interface.

Alan Cone - Continued search for library materials.

Frank Garolera - Considered alternate interface designs, and developed interface locking mechanism.

David German - Considered alternate hook designs.

Dave Lindabury - Developed CAD drawing of interface.

Cleve Luckado - Helped develop formal problem definition and used CAD.

Craig Murphey - Assisted in CAD use.

Bryan Rowell - Helped develop formal problem definition.

Brad Wilkinson - Aided in search for background information on interface.

TO: Mr. J. W. Brazell
FROM: Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
SUBJECT: Progress report for week of April 25, 1988.

The group is currently in the information gathering mode of the design process. Hook-up motions were defined for the interface and it was decided that a latch or sliding hook must be used on all three points of attachement. In addition the following was accomplished:

Will Cash - Developed interface locking mechanism.

Alan Cone - Met with library personell and disscussed data base search.

Frank Garolera - Further design consideration on crane hook.

David German - Helped in data base search.

Dave Lindabury - Continued CAD work.

Cleve Luckado - Aided in crane hook development and CAD work.

Craig Murphey - Helped with CAD.

Bryan Rowell - Continued with search for materials.

Brad Wilkinson - Considered possible interface locking mechanisms.

TO: Mr. J. W. Brazell
FROM: Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
SUBJECT: Progress report for week of May 2, 1988.

The format for the mid-term presentation was decided upon and color slides will be used of Apollo CAD drawings. Latching mechanisms were discussed. A final idea was decided for each the interface and crane hook in order to start analysis.

<u>Will Cash</u> - Created design matrix for interface designs and latch drawings for presentation.

<u>Alan Cone</u> - Directing library search and researching alternative designs.

<u>Frank Garolera</u> - Researching lunar effects on designs, physical model group member, helped with computer optimization.

<u>David German</u> - Coordinating data base search and physical model group member.

<u>Dave Lindabury</u> - Continuing Apollo CAD work and developing slides for presentation.

<u>Cleve Luckado</u> - Standardizing report formats, creating mechanical drawings, and physical model group member.

<u>Craig Murphey</u> - Personal computer work, Apollo modeling, and slide development.

<u>Bryan Rowell</u> - Researching all old design reports for interesting information and load parameter of previous groups.

<u>Brad Wilkinson</u> - Servo-actuator research , developed mechanical drawings of interface, and physical model group member.

TO: Mr. J. W. Brazell
FROM: Design Group # 7. (SKITTER/Implement Mechanical Interface and Crane Hook Design).
SUBJECT: Progress report for the week of May 16, 1988.

Will Cash - Continued on the improvement of the latch design, and worked on the sizing of latch components for strength and minimum deflections.

Alan Cone - Searched and organized tools that will be required for the development of the physical models.

Frank Garolera - Participated in the search for suitable building materials for the mechanical interface, and edited the weekly progress report.

David German - Participated in the continuing design of the interface mechanism and the development of the physical models.

Dave Lindabury - Continued with the processing of the finite element analysis for the new crane hook design.

Cleve Luckado - Located materials for the fabrication of a physical model for the crane hook and initiated fabrication.

Craig Murphey - Assisted Cleve Luckado in identifying and locating possible materials for the fabrication of a physical model for the crane hook.

Bryan Rowell - Assisted in the search of possible materials for the construction os the mechanical interface for SKITTER.

Brad Wilkinson - Assisted in the continuing design of the latching mechanism and the search of possible alternatives for a physical model.

TO: Mr. J. W. Brazell

FROM: Design Group # 7. (SKITTER/Implement Mechanical Interface and Crane Hook Design).

SUBJECT: Progress report for the week of May 23, 1988.

Will Cash - Further work on actual sizing of latch components. Drawing for latch component. Compiled a portion of the rough draft. Research possible bearings for the latch.

Alan Cone - Assisted on the design of the new interface. Worked on rough draft and interface model.

Frank Garolera - Obtained data on materials for the design of interface and crane hook. Compiled and edited portions of the rough draft.

David German - Worked on the rough draft for the crane hook, and came up with alternative design for crane hook.

Dave Lindabury - Continued the process of finite element modeling for the crane hook. Established node-element model of hook on Apollo which will be transferred to F.E.A. solution and optimization.

Cleve Luckado - Assisted in the completion of crane hook model, and started the fabrication of interface model. Assisted in preparing the rough draft.

Craig Murphey - Obtained materials for crane hook model and for interface model. Finished crane hook model. Researched on actuators for actual designs.

Bryan Rowell - Researched material constraints for the construction of interface model. Also found several materials that meet design requirements. Worked on sections of rough draft.

Brad Wilkinson - Worked on the crane hook model and the design of the new interface/latching mechanism design. Assisted in the organization of rough draft.

TO: Mr. J. W. Brazell
FROM: Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
SUBJECT: Progress report for week of May 30, 1988

Will Cash - Wrote text on latch components analysis and specifications, also assisted in production of latch model.

Alan Cone - Wrote and edited parts of crane hook report and assisted in production of interface model.

Frank Garolera - Edited parts of interface report and produced MacDraw figures to accompany component descriptions.

David German - Wrote and edited parts of crane hook report and edited all prior progress reports.

Dave Lindabury - Ran two FEA's on different crane hook designs, analyzed data for alternate solutions, and prepared slides for presentation.

Cleve Luckado - Wrote parts of both reports, produced CAD drawings for interface, and assisted in production of interface model.

Craig Murphey - Wrote parts of crane hook report and assisted in completing both models.

Bryan Rowell - Worked on materials, abstract, conclusions, and failure of interface report and prepaired for presentation.

Brad Wilkinson - Assisted in analysis of latch mechanism.

APPENDIX A2
FIGURES.

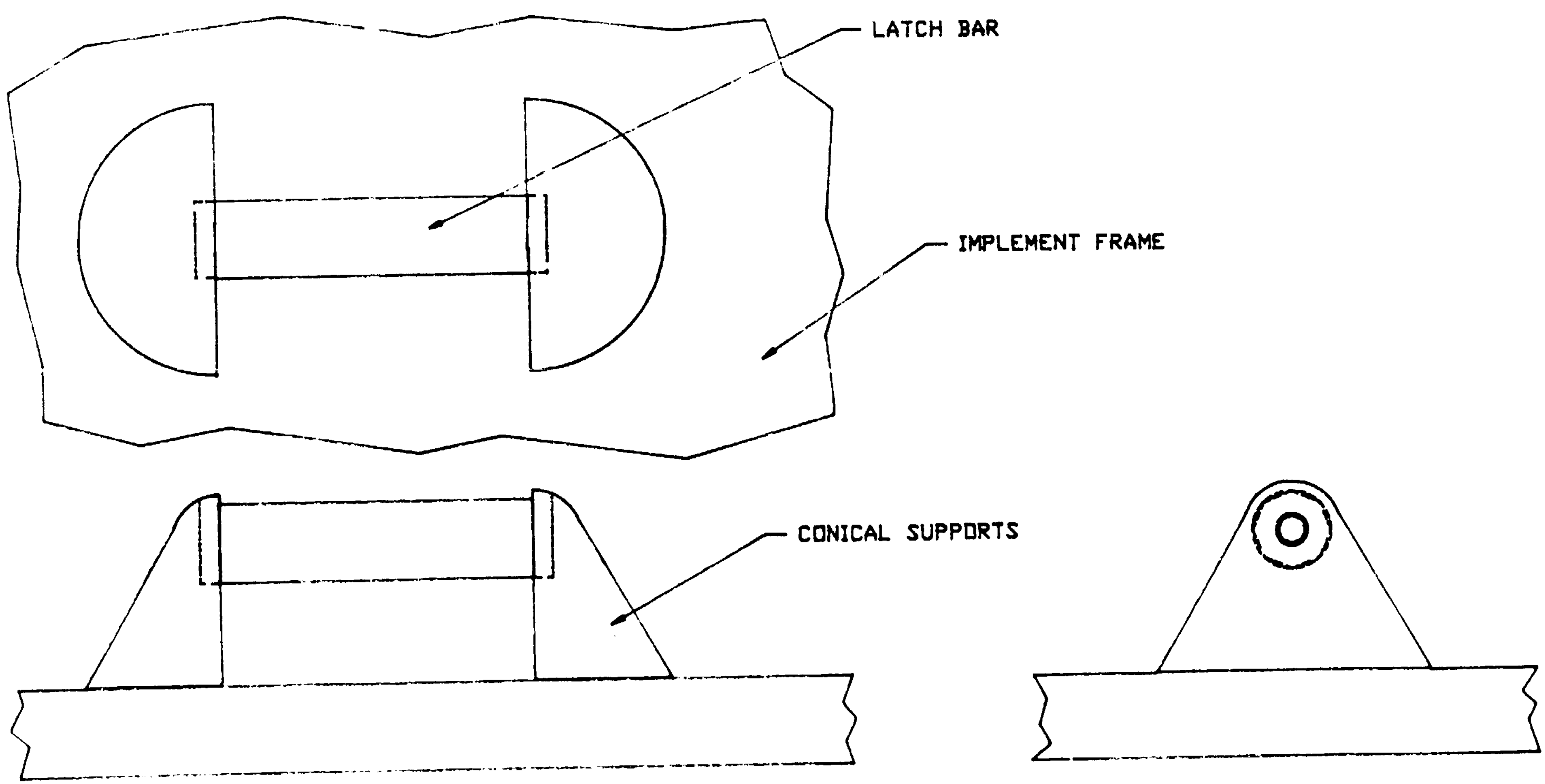
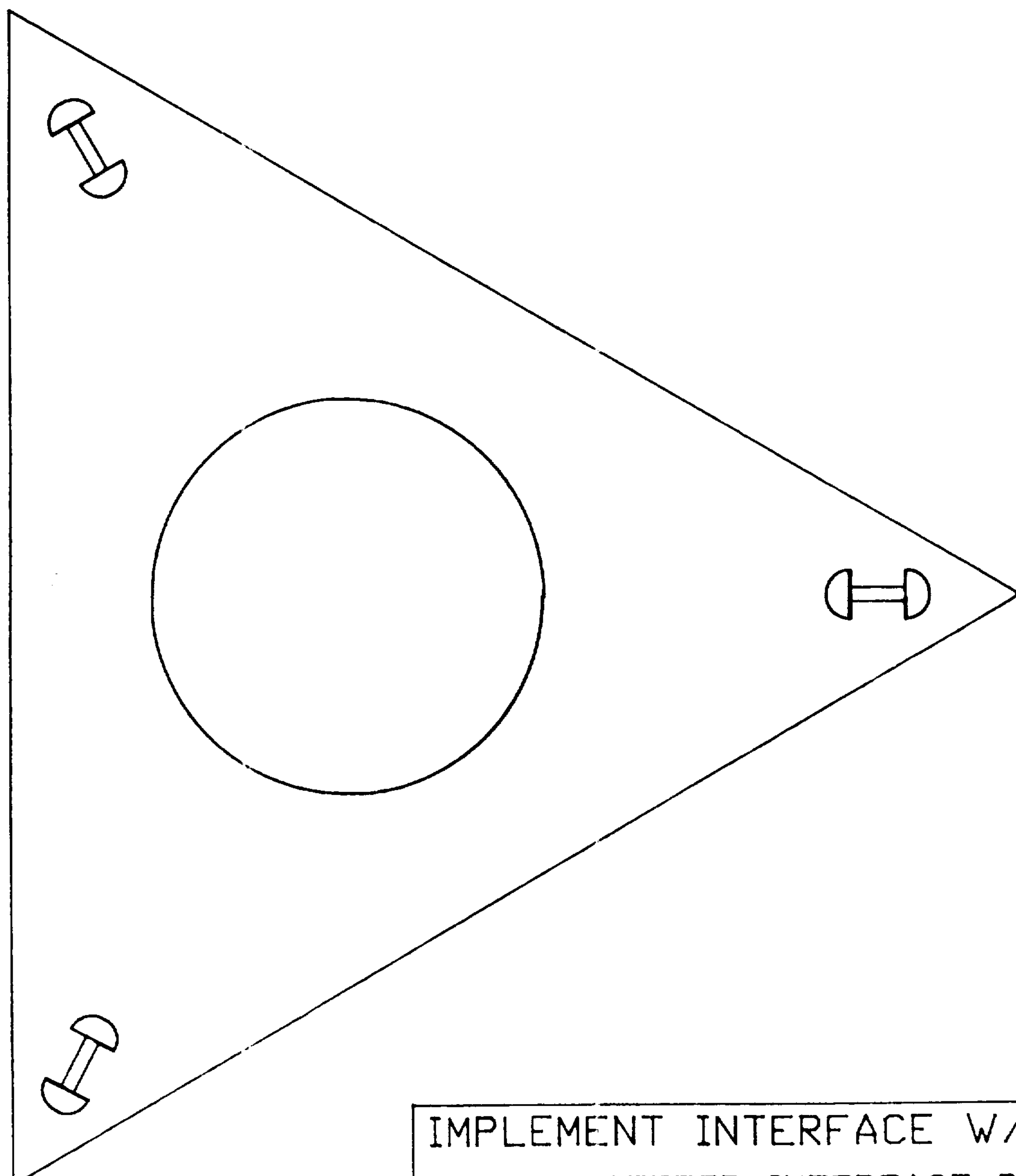


FIGURE # 3

IMPLEMENT FOOT
ME4182 SKITTER INTERFACE PROJECT
GROUP #7 5/28/88

IMPLEMENT INTERFACE

FIGURE # 4



IMPLEMENT INTERFACE W/ FEET
ME4182 SKITTER INTERFACE PROJECT
GROUP #7 5/26/88

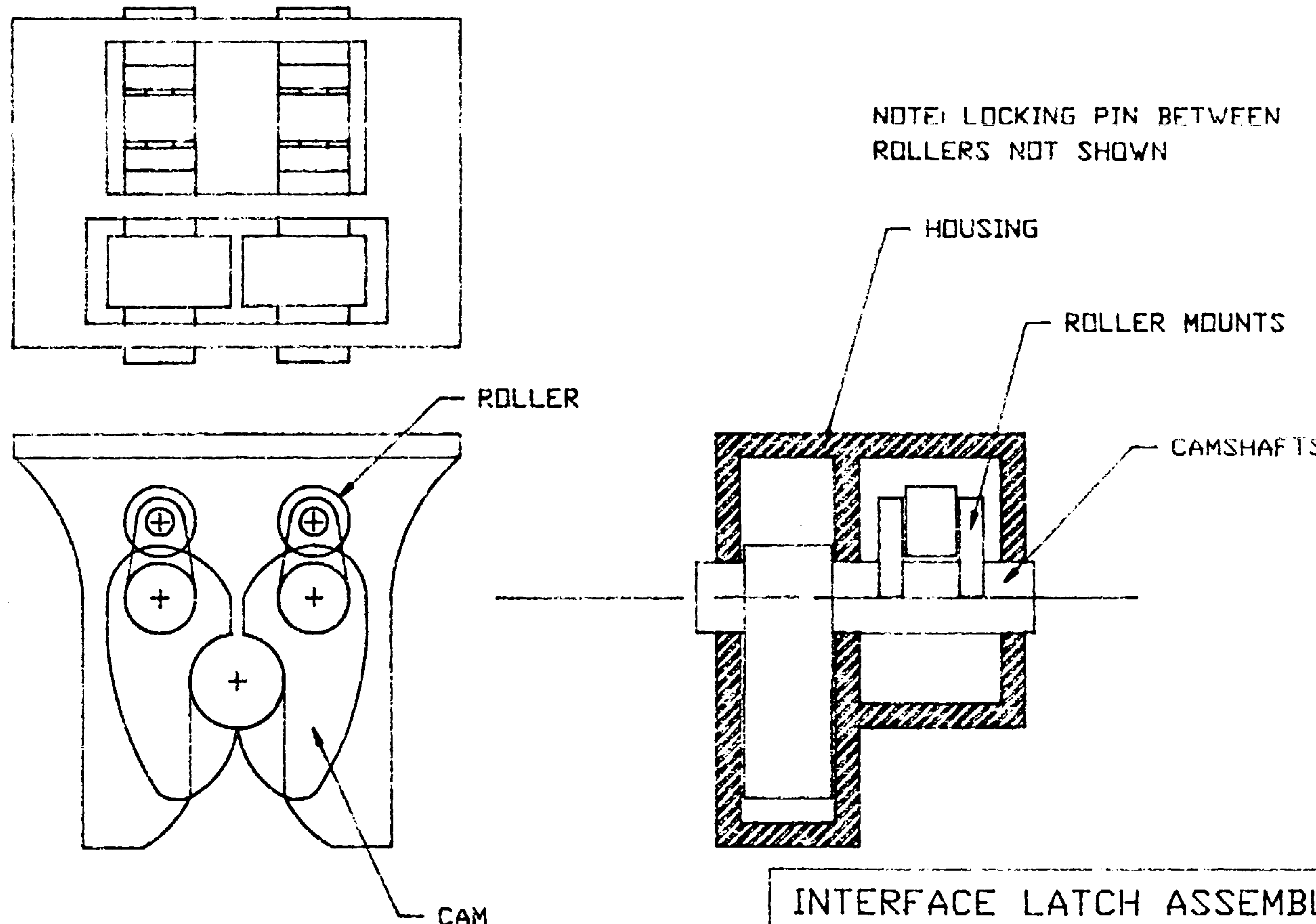


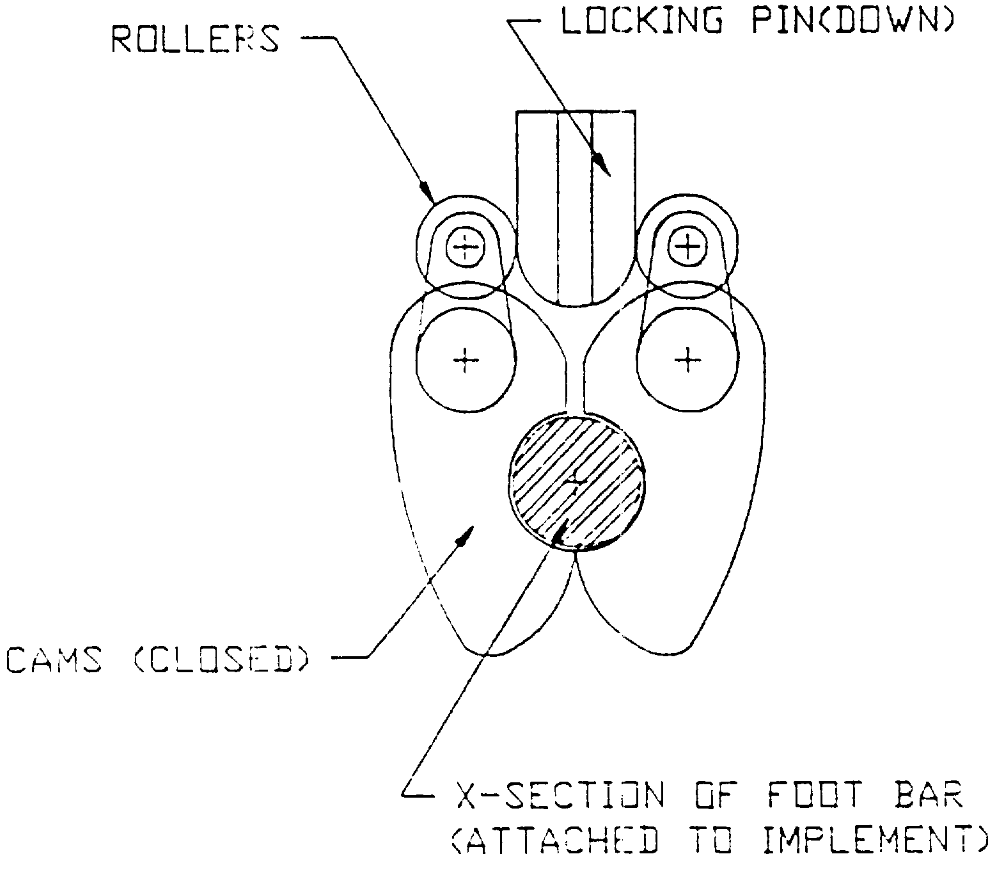
FIGURE #6

INTERFACE LATCH ASSEMBLY

ME4182 SKITTER INTERFACE PROJECT
GROUP #7 5/28/88

LATCH IN LOCKED POSITION

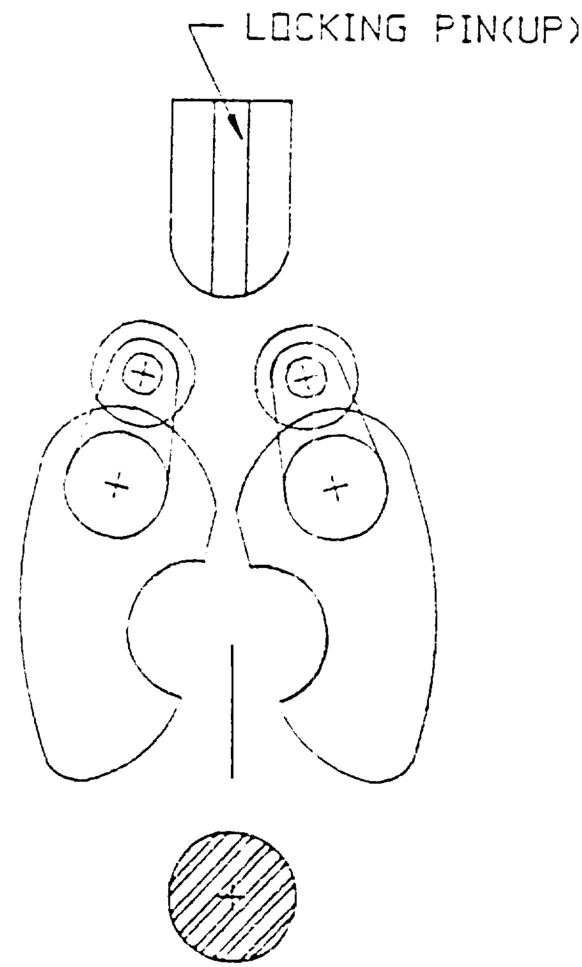
FIGURE #7 A



ME4182 SKITTER INTERFACE PROJECT
GROUP #7 5/28/88

LATCH IN OPEN POSITION

FIGURE #7 B



ME 4182 SKITTER INTERFACE PROJECT
GROUP #7 5/28/88

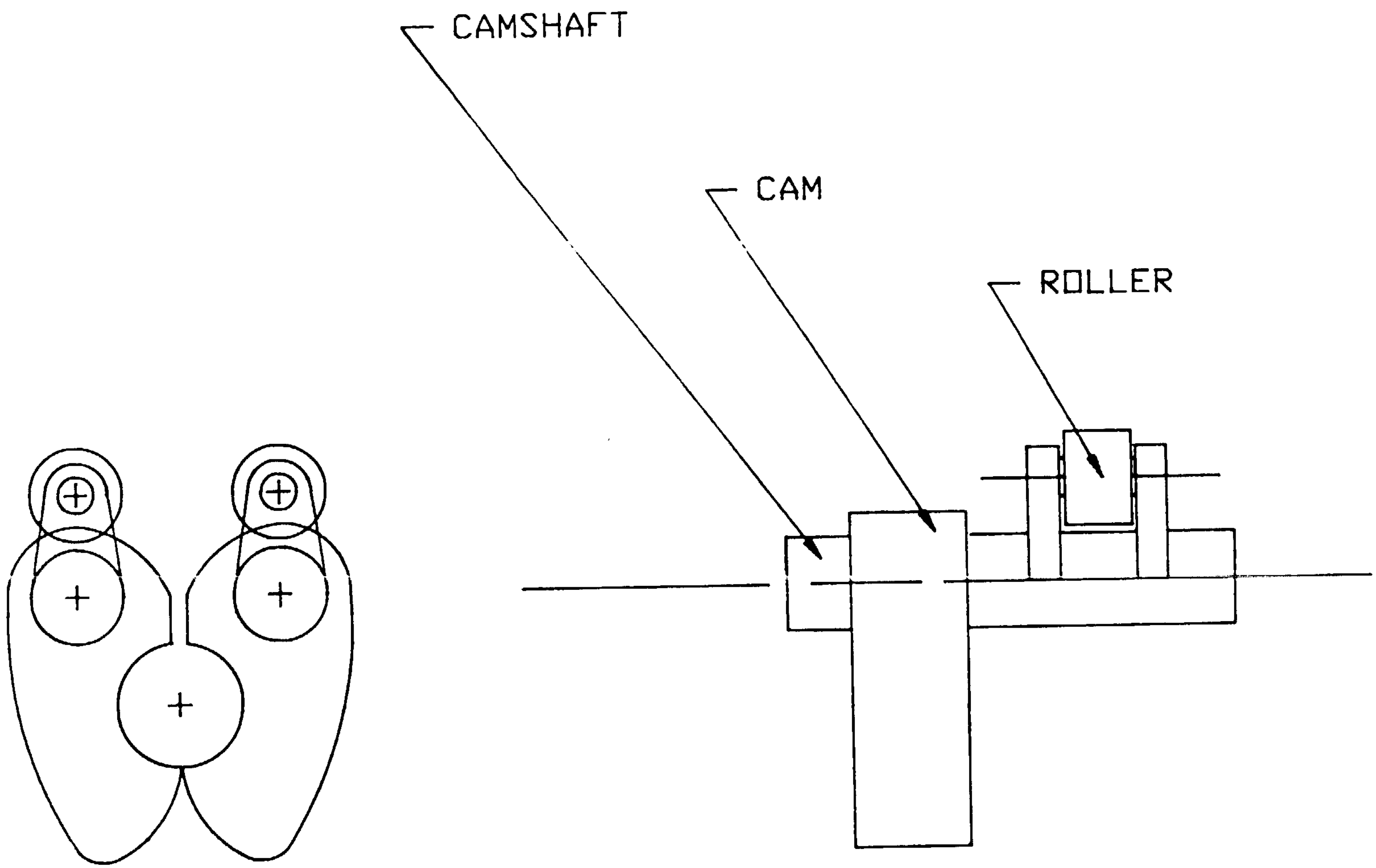


FIGURE # 8

CAMS,CAMSHAFTS, AND ROLLERS

ME4182 SKITTER INTERFACE PROJECT
GROUP #7 5/28/88

FIGURE 9 - LOCKING PIN

Side View

Top View

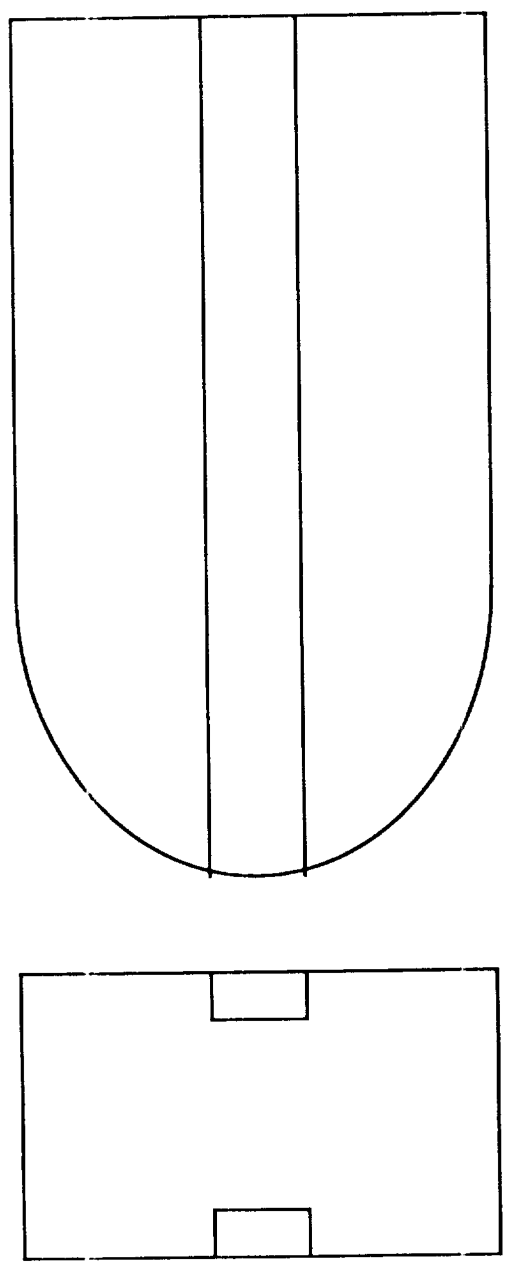
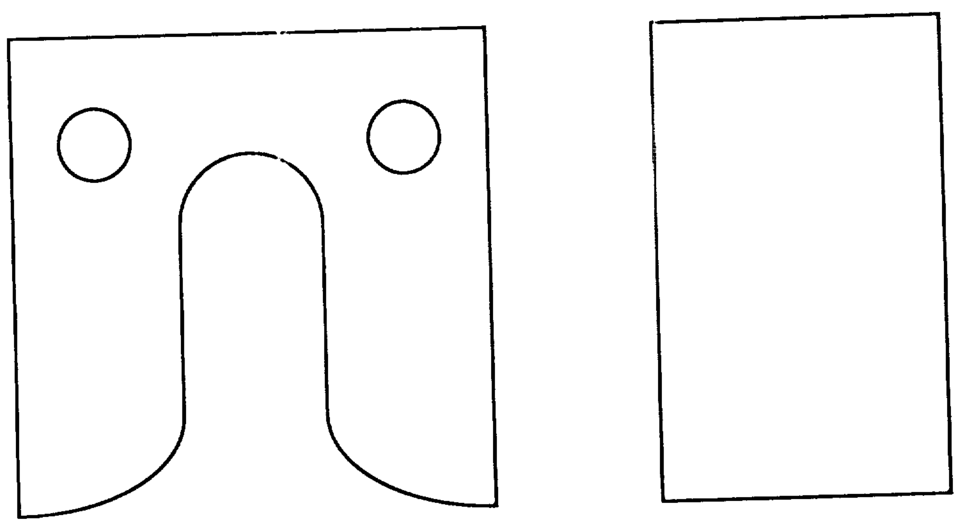


FIGURE 10. HOUSING PLATES



APPENDIX B1
DESIGN MATRIX.

SKITTER/IMPLEMENT INTERFACE - DESIGN MATRIX
ME 4182 GROUP 7 SPRING '88

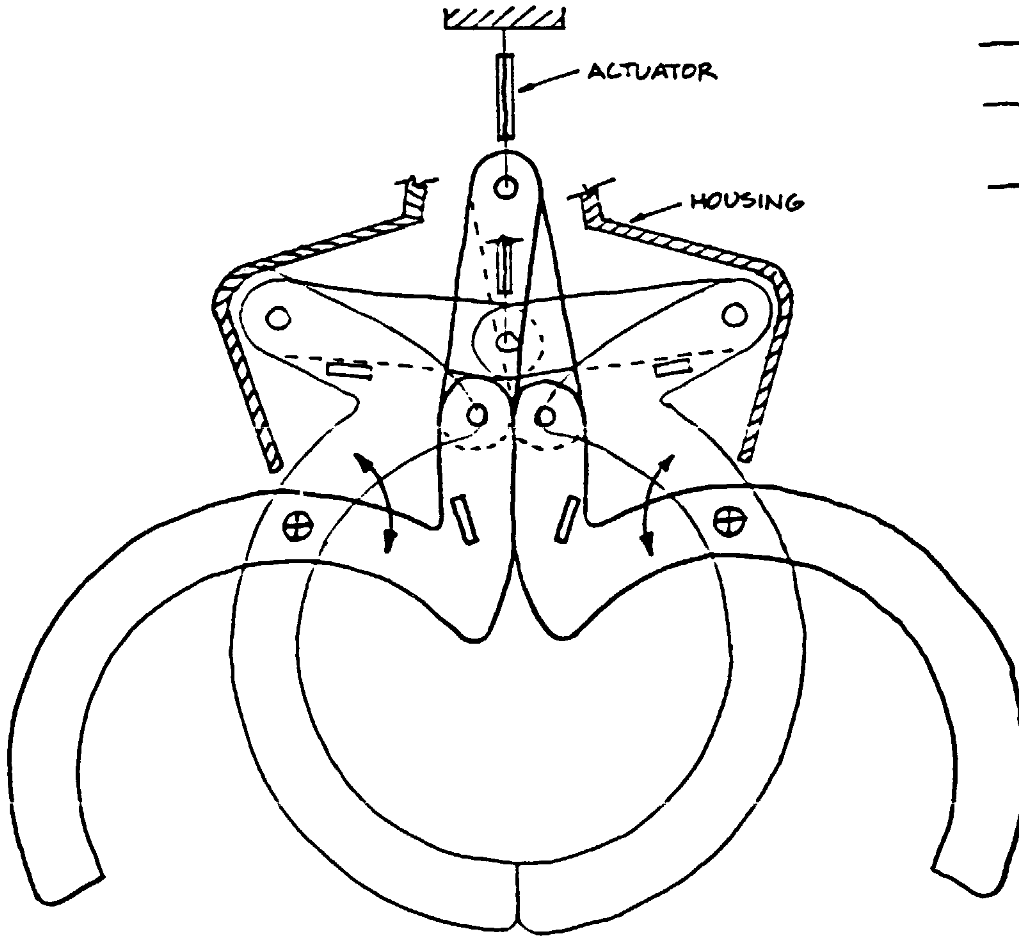
DESIRABLE LATCH CHARACTERISTIC

1. MIN SPACE	7. MIN POWER REQ
2. FEW MOVING PARTS	8. SELF GUIDING
3. LOW WEIGHT	9. USE FORCES EFF.
4. DIRT TOLERANT	10. EASE OF ENTRY & EXIT
5. TEMP EXTREMES	11. OPER IN VACUUM
6. MIN SLIDING FRICTION	12. SECURE

CHAR>	1	2	3	4	5	6	7	8	9	10	11	12	SCORE
WEIGHT>	1	1	1	1	1	1	1	1	1	1	1	1	120MAX
CAM	4	6	7	7	8	8	4	6	5	9	9	8	81
SCREW	7	6	7	4	8	3	4	4	6	3	9	8	69
PIN	7	6	7	4	8	5	7	5	5	4	9	8	75
CLAMP	5	5	7	7	8	6	5	5	5	7	9	8	77
RR HITCH	5	7	7	8	8	5	5	6	6	6	9	8	80
5TH WHEEL	5	5	7	7	8	5	5	7	8	7	9	8	81
TRAILER H	5	6	7	7	8	7	5	7	6	7	9	8	82
VELCRO	7	9	5	7	3	9	9	6	3	4	9	4	75
TENSION	5	5	7	7	8	6	5	6	9	8	9	8	83
CAR DOOR	5	5	7	7	8	5	5	7	5	6	9	8	77
MAGNETIC	7	9	3	4	8	9	2	9	2	9	9	6	77
CABINET	7	9	4	8	7	4	5	8	4	5	9	4	74
SUCTION	6	6	7	3	5	9	5	4	6	9	1	6	67
GLUE	8	9	7	4	4	9	9	4	3	1	4	9	71
FRICTION	4	5	5	4	7	6	4	5	9	5	9	7	70

APPENDIX B2
SET OF DRAWINGS / SKETCHES FOR ALTERNATIVE DESIGNS.

POSSIBLE CONNECTIONS:



— OPEN POSITION
— CLOSED & LOCKED POSITION
— FIXED PARTS

EXPLANATION:

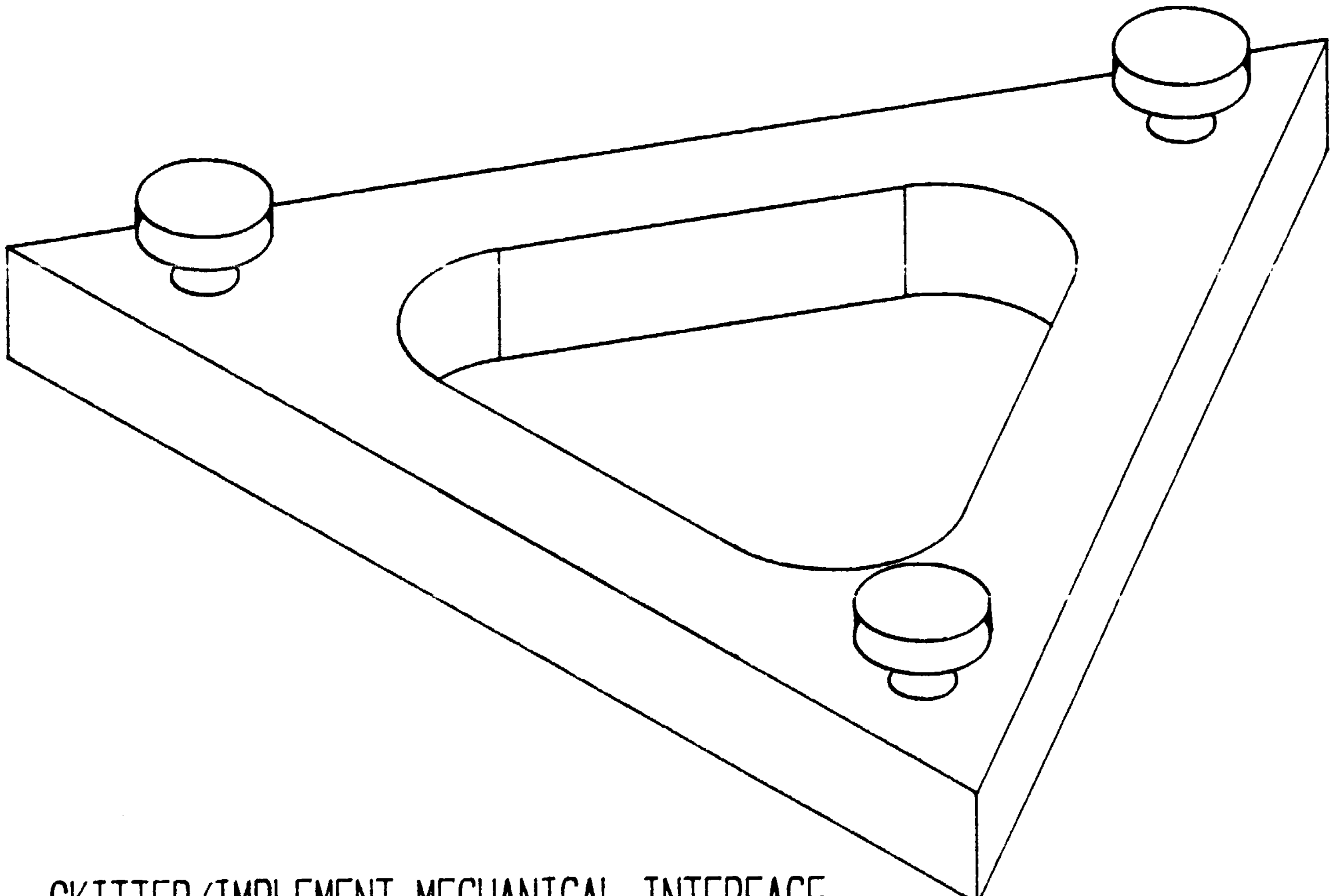
WHILE THE LATCH IS IN THE OPEN POSITION, SKITTER MANEUVERS TO GUIDE THE IMPLEMENT CONNECTION INTO THE LATCH. THE MOTION OF THE CONNECTION CAUSES THE LATCH TO BEGIN CLOSING. THE ACTUATOR PUSHES TO LOCK THE LINKAGE INTO PLACE BY USING DEFLECTION. TO RELEASE THE IMPLEMENT. THE ACTUATOR PULLS TO UNLOCK AND, THE CONNECTION PULLS OUT TO OPEN THE LATCH.

SKITTER/IMPLEMENT LATCH

N.T.S.

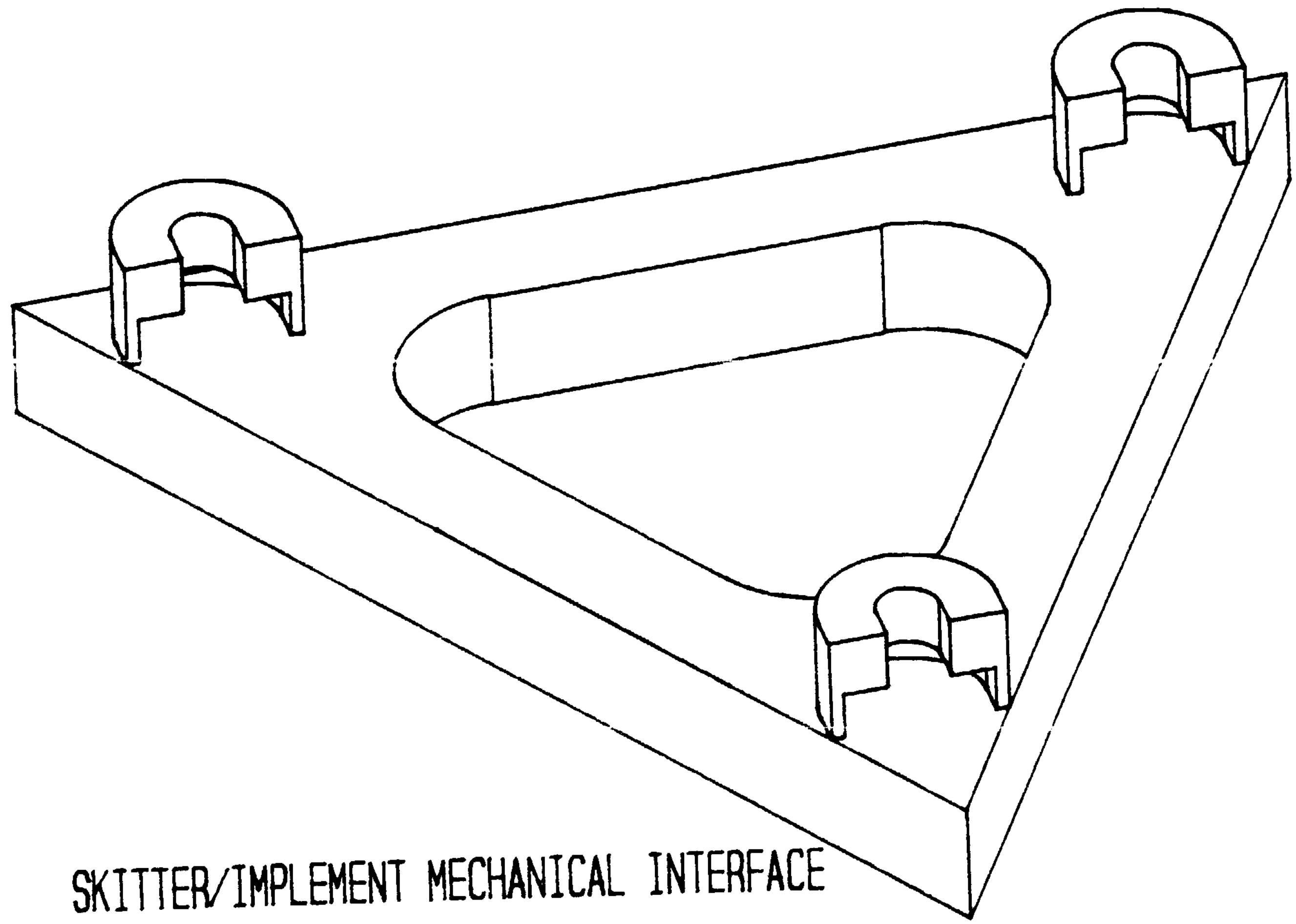
ME 4182
4-28-88
W. CASH

4/21



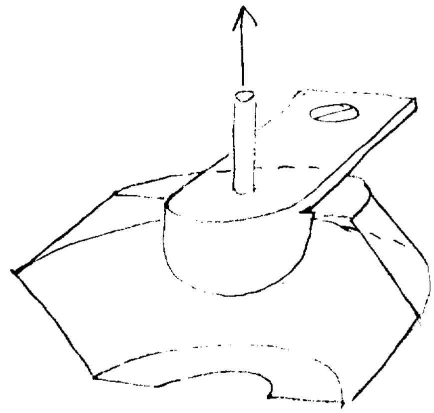
SKITTER/IMPLEMENT MECHANICAL INTERFACE
IMPLEMENT SIDE

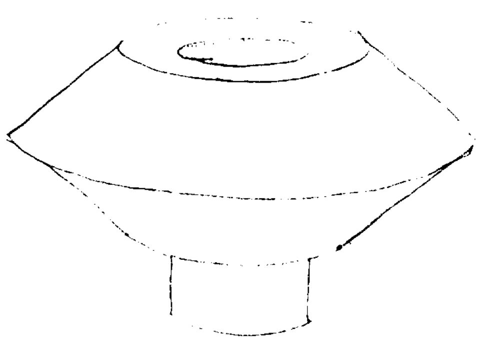
4/21

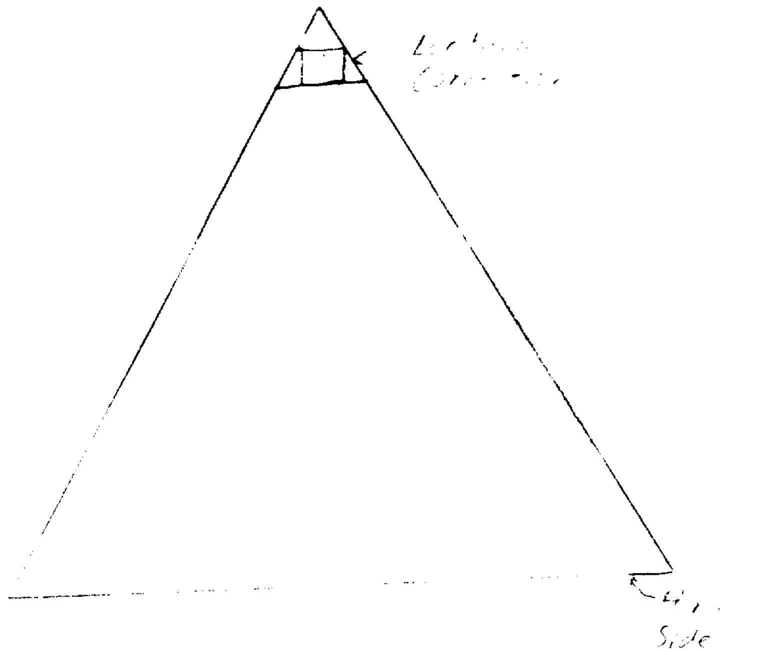


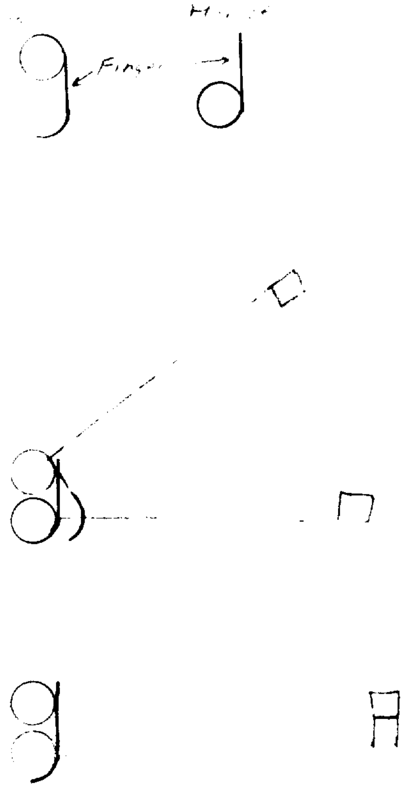
SKITTER/IMPLEMENT MECHANICAL INTERFACE
SKITTER SIDE

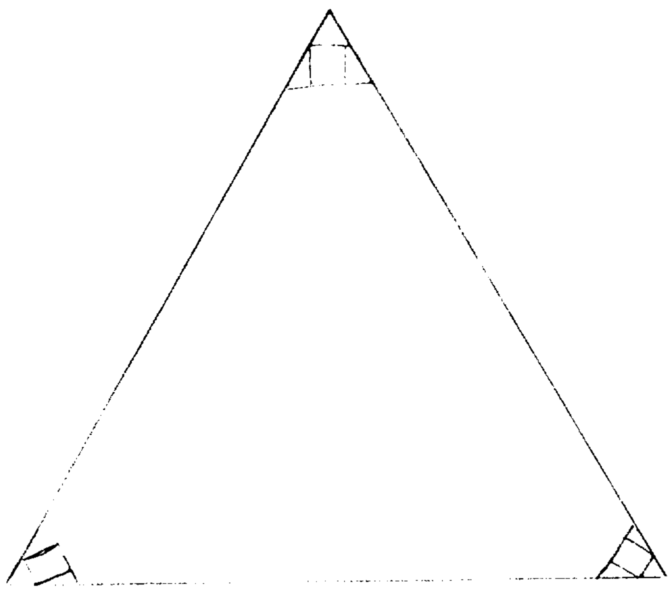
4/21



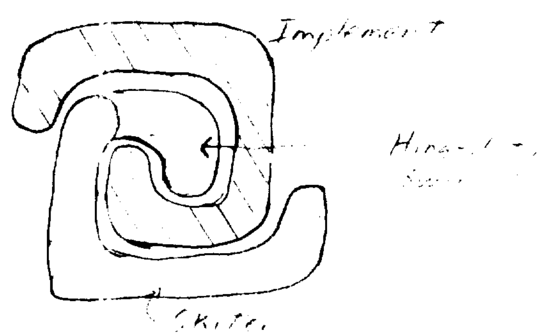



Side





Th[illegible] lock[illegible] conn[illegible]
similar to [illegible] lock connections
active on skitter



FRANK GAROLERA

I. INTERFACE FOR SKITTER:

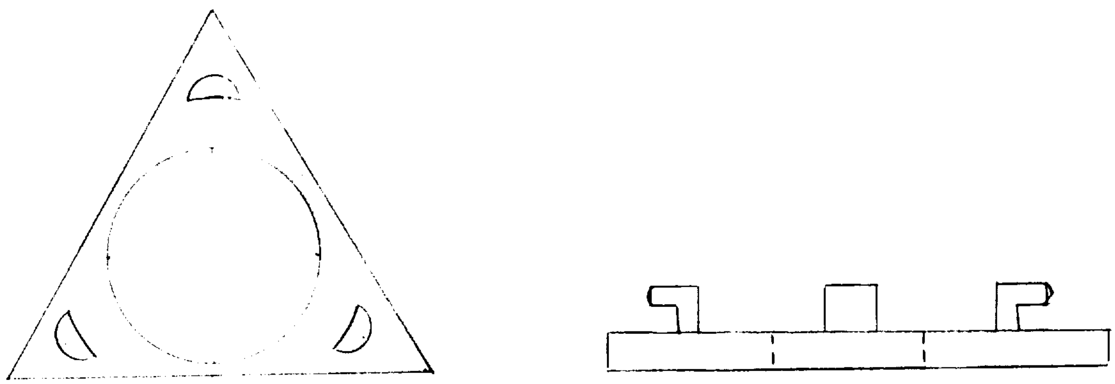
The interface for skitter consists of a fixed, circular part on the inside (1) and two moving semicircular parts on the outside (2). The two semicircular parts are activated by hydrolic or pneumatic cylinders.

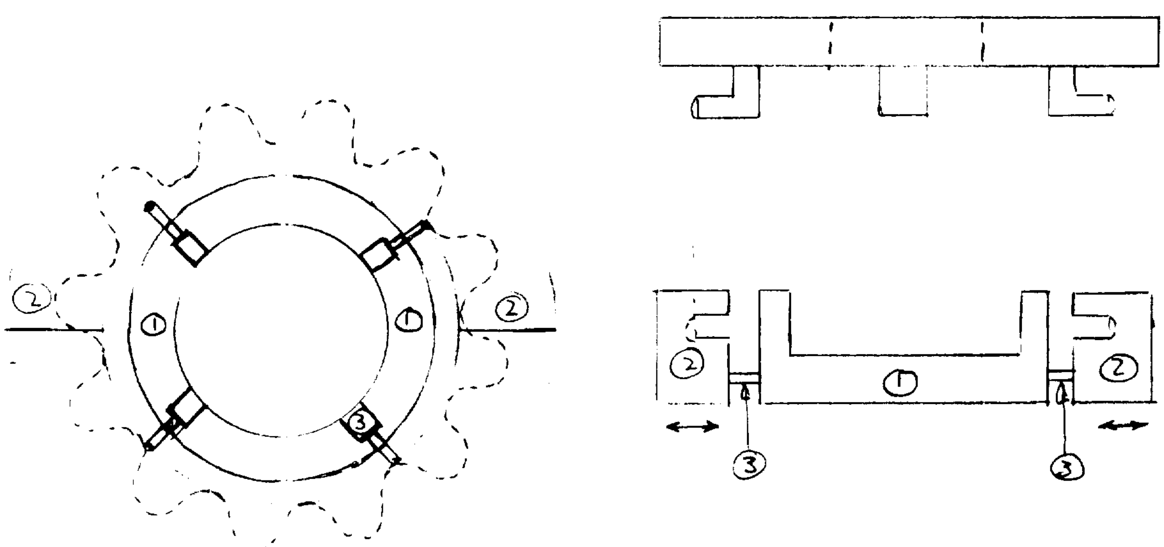
II. CONNECTING IMPLEMENT FOR CRANE

The connecting implement will easily couple and accurately engage. The concern for approaching the male fitting to the female fitting is only in one direction. The energy necessary to complete the approach is supply by gravitational force.

FRANK GARKOLERA

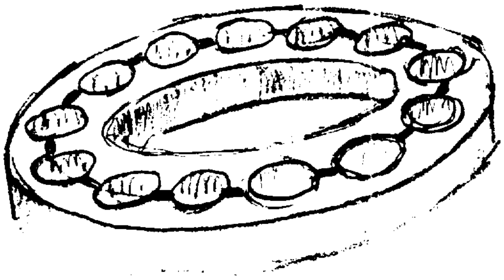
I. INTERFACE FOR SKITTER

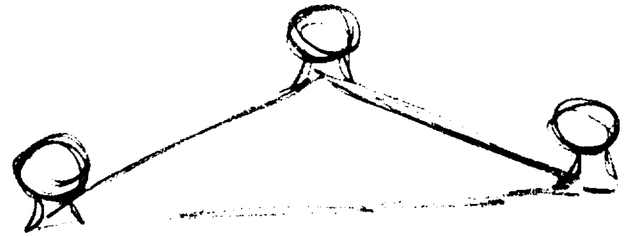


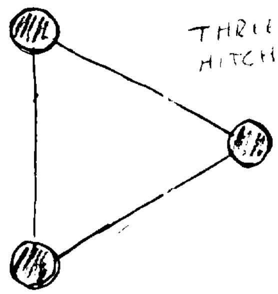


TOP

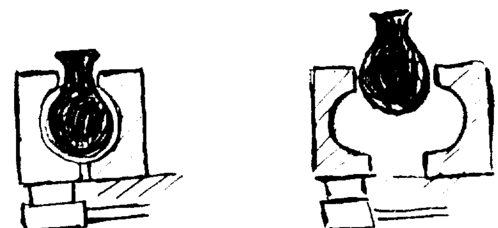
SIDE







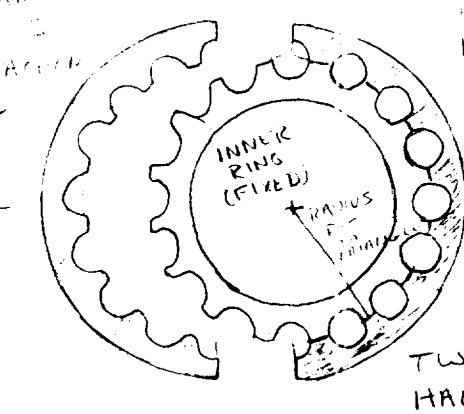
SECTION

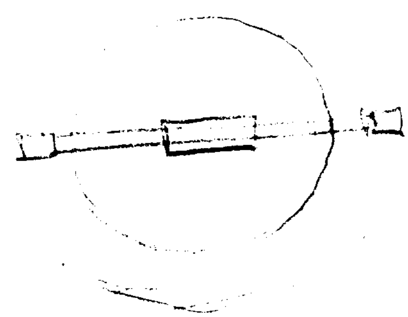


TOP

① RINGS ARE

② RINGS ARE IN. HITCHES HAVE NO VERTICAL OR ROTATIONAL MOTION

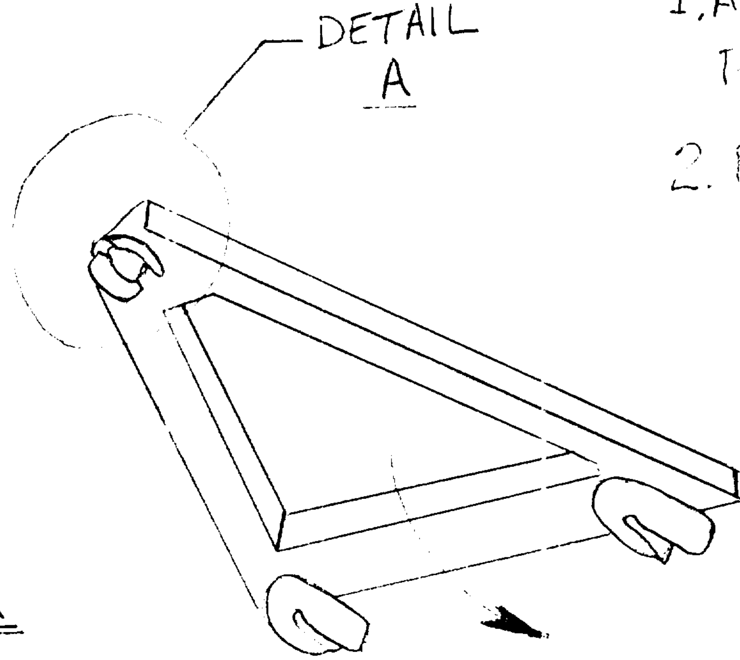




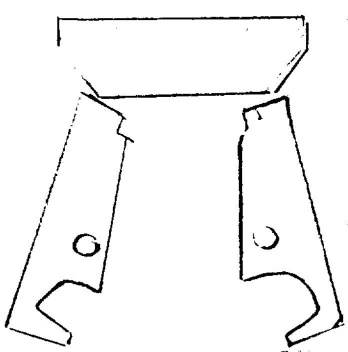
* THE THREE HITCHES [illegible] ATTACH AT MULTIPLE POINTS AROUND RING. EASY ALIGNMENT
* ONCE RINGS LOCK IN, NO ROTATIONAL OR VERTICAL MOTION IS POSSIBLE.

SKITTER INTERFACE

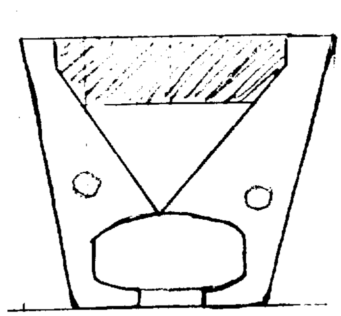
1. ACTIVE HITCH POINT
2. PASSIVE POINTS



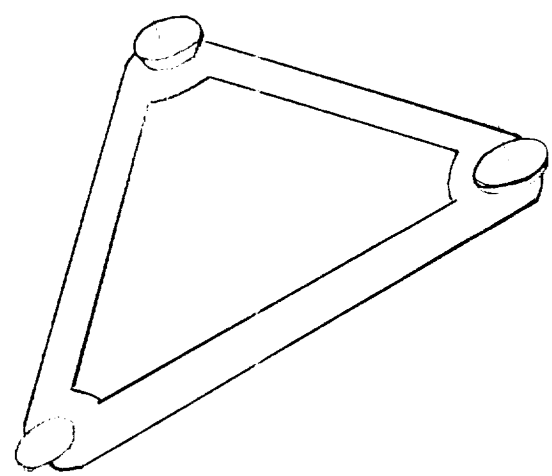
DETAIL A



OPEN

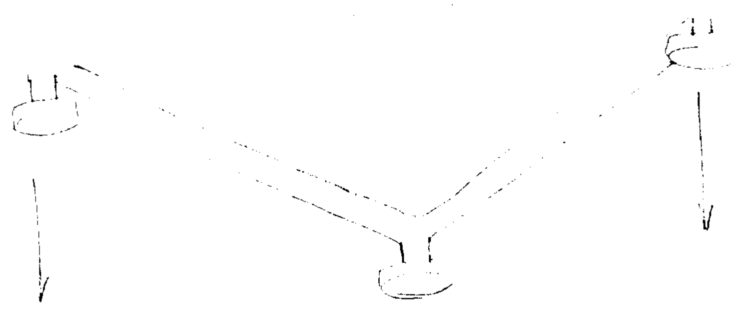


CLOSED &
LOCKED

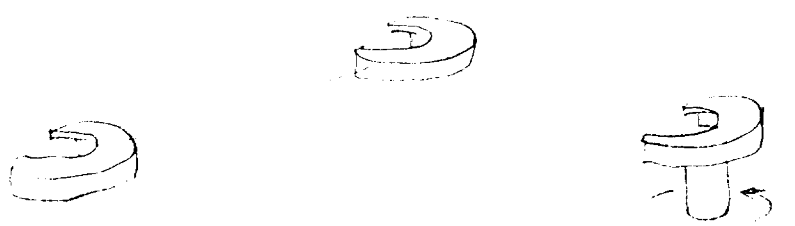


GROUP #7

ANOTHER IDEA



IMPLEMENT SIDE
(TO BE MOUNTED)



SKITTER MANEUVERS NEXT TO THE IMPLEMENT. IT THEN PERFORMS A SLIDING MOTION TO COUPLE THE PINS WITH THEIR HOUSINGS. ONE HOUSING THEN ROTATES 180° TO LOCK THE PINS IN PLACE.

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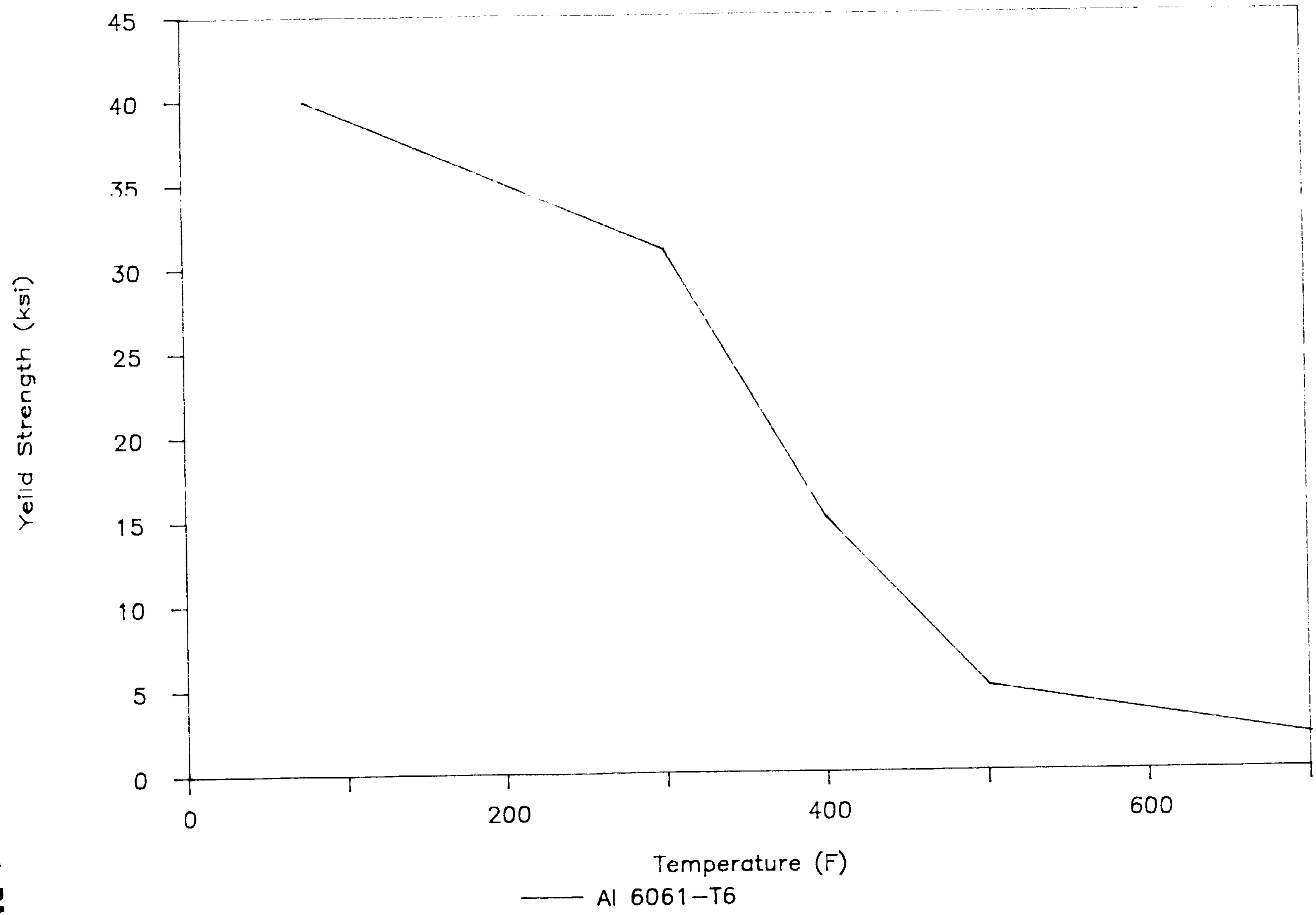
APPENDIX C1
Sy vs. T FOR AL 6061-T6

Figure [illegible]

STRENGTH PROFILE

ME 4182 GROUP7 6-01-88



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OF POOR QUALITY

APPENDIX C2
AL 6061-T6 PROPERTIES

Table 1 Product forms and nominal compositions of common wrought aluminum alloys

AA number	Product(a)	Composition, % Al	Si	Cu	Mn	Mg	Cr	Zn	Others
1050	DT	99.50 min	...	...	...	...	...	...	...
1060	S, P, ET, DT	99.60 min	...	...	...	...	...	...	...
1100	S, P, F, E, ES, ET, C, DT, FG	99.00 min	...	0.12	...	...	...	...	...
1145	S, P, F	99.45 min	...	...	...	...	...	...	...
1199	F	99.99 min	...	...	...	...	...	...	...
1350	S, P, E, ES, ET, C	99.50 min	...	...	...	...	...	...	...
2011	E, ES, ET, C, DT	93.7	...	5.5	...	...	...	...	0.4Bi; 0.4Pb
2014	S, P, E, ES, ET, C, DT, FG	93.5	0.8	4.4	0.8	0.5	...	...	...
2024	S, P, E, ES, ET, C, DT	93.5	...	4.4	0.6	1.5	...	...	...
2036	S	96.7	...	2.6	0.25	0.45	...	...	...
2048	S, P	94.8	...	3.3	0.4	1.5	...	...	...
2124	P	93.5	...	4.4	0.6	1.5	...	...	...
2218	FG	92.5	...	4.0	...	1.5	...	...	2.0Ni
2219	S, P, E, ES, ET, C, FG	93.0	...	6.3	0.3	...	...	...	0.06Ti; 0.10V; 0.18Zr
2319	C	93.0	...	6.3	0.3	...	...	...	0.18Zn, 0.15Ti; 0.10V
2618	FG	93.7	0.18	2.3	...	1.6	...	...	1.1Fe; 1.0Ni; 0.07Ti
3003	S, P, F, E, ES, ET, C, DT, FG	98.6	...	0.12	1.2	...	...	...	...
3004	S, P, ET, DT	97.8	...	...	1.2	1.0	...	...	...
3105	S	99.0	...	...	0.55	0.50	...	...	...
4032	FG	85.0	12.2	0.9	...	1.0	...	...	0.9Ni
4043	C	94.8	5.2	...	...	...	...	...	...
5005	S, P, C	99.2	...	...	...	0.8	...	...	...
5050	S, P, C, DT	98.6	...	...	...	1.4	...	...	...
5052	S, P, F, C, DT	97.2	...	...	...	2.5	0.25	...	...
5056	F, C	95.0	...	...	0.12	5.0	0.12	...	...
5083	S, P, E, ES, ET, FG	94.7	...	...	0.7	4.4	0.15	...	...
5086	S, P, E, ES, ET, DT	95.4	...	...	0.4	4.0	0.15	...	...
5154	S, P, E, ES, ET, C, DT	96.2	...	...	...	3.5	0.25	...	...
5182	S	95.2	...	...	0.35	4.5	...	...	...
5252	S	97.5	...	...	...	2.5	...	...	...
5254	S, P	96.2	...	...	...	3.5	0.25	...	...
5356	C	94.6	...	...	0.12	5.0	0.12	...	0.13Ti
5454	S, P, E, ES, ET	96.3	...	...	0.8	2.7	0.12	...	...
5456	S, P, E, ES, ET, DT, FG	93.9	...	...	0.8	5.1	0.12	...	...
5457	S	98.7	...	...	0.3	1.0	...	...	...
5652	S, P	97.2	...	...	...	2.5	0.25	...	...
5657	S	99.2	...	...	...	0.8	...	...	...
6005	E, ES, ET	98.7	0.8	...	...	0.5	...	...	...
6009	S	97.7	0.8	0.35	0.5	0.6	...	...	...
6010	S	97.3	1.0	0.35	0.5	0.8	...	...	...
6061	S, P, E, ES, ET, C, DT, FG	97.9	0.6	0.28	...	1.0	0.2	...	...
6063	E, ES, ET, DT	98.9	0.4	...	...	0.7	...	...	...
6066	E, ES, ET, DT, FG	95.7	1.4	1.0	0.8	1.1	...	...	...
6070	E, ES, ET	96.8	1.4	0.28	0.7	0.8	...	...	...
6101	E, ES, ET	98.9	0.5	...	...	0.6	...	...	...
6151	FG	98.2	0.9	...	...	0.6	0.25	...	...
6201	C	98.5	0.7	...	...	0.8	...	...	...
6205	E, ES, ET	98.4	0.8	...	0.1	0.5	0.1	...	0.1Zr
6262	E, ES, ET, C, DT	96.8	0.6	0.28	...	1.0	0.09	...	0.6Bi; 0.6Pb
6351	E, ES	97.8	1.0	...	0.6	0.6	...	...	...
6463	E, ES	98.9	0.4	...	...	0.7	...	...	...
7005	E, ES	93.3	...	...	0.45	1.4	0.13	4.5	0.04Ti; 0.14Zr
7049	P, E, ES, FG	88.2	...	1.5		2.5	0.15	7.6	...
7050	P, E, ES, FG	89.0	...	2.3	...	2.3	...	6.2	0.12Zr
7072	S, F	99.0	...	...	...	...	...	1.0	...
7075	S, P, E, ES, ET, C, DT, FG	90.0	...	1.6	...	2.5	0.23	5.6	...
7175	S, P, FG	90.0	...	1.6	...	2.5	0.23	5.6	...
7178	S, P, E, ES, C	88.1	...	2.0	...	2.7	0.26	6.8	...
7475	S, P, FG	90.3	1.5	...	...	2.3	0.22	5.7	...

(a) S = sheet; P = plate; F = foil; E = extruded rod, bar and wire; ES = extruded shapes; ET = extruded tubes; C = cold finished rod, bar and wire; DT = drawn tube; FG = forgings.

Table 4 (continued)

Alloy	Temper	Electrical conductivity(a) Volume	Weight	Electrical resistivity(b) nΩm	ohms(d)	Thermal conductivity(c) W/mK	Btu/ft·h·°F
6005	T5	49	162	35	21	167	97
6009	O	54	184	32	19	205	118
	T4	44	150	39	24	172	99
	T6	47	160	37	22	180	104
6010	O	53	175	33	20	202	117
	T4	39	129	44	27	151	87
	T6	44	146	39	24	180	104
6061	O	47	155	37	22	180	104
	T4	40	132	43	26	154	89
	T6	43	142	40	24	167	97
6063	O	58	191	30	18	218	126
	T1	50	165	35	21	193	112
	T5	55	181	32	19	209	121
	T6	53	175	33	20	201	116
6066	O	40	132	43	26	147	85
	T6	37	122	47	28	147	85
6070	T6	44	145	39	24	172	99
6101	T6	57	188	30	18	218	138
	T8	54	178	32	19	218	138
6151	O	54	178	32	19	205	118
	T4	42	138	41	25	163	94
	T6	45	148	38	23	175	101
6201	T81	54	179	32	19	205	118
6205	T1	45	149	37	22	172	99
	T5	49	162	35	21	188	109
6262	T9	44	145	39	24	172	99
6351	T6	46	152	38	23	176	102
6463	T1	50	165	34	21	192	111
	T5	55	181	31	19	209	121
	T6	53	175	33	20	201	116
7005	O	43	138	40	24	166	96
	T53	38	122	45	27	148	86
	T6	35	113	49	30	137	79
	T63	38	122	45	27	148	86
7049	T73	38	120	43	27	154	89
7050	O	47	148	37	22	180	104
	T73	40	127	43	26	157	91
	T76	40	125	44	26	154	89
7072	O	60	197	29	17	227	131
7075	T6	33	105	52	31	130	75
	T73	40	128	43	26	155	90
	T76	38	123	45	27	150	87
7175	O	46	147	38	23	177	102
	T66	36	115	48	29	142	82
	T73	40	128	43	26	155	90
7475	O	46	147	38	23	177	102
	T6	36	115	48	29	142	82
	T7351	40	128	43	26	155	90
	T76	42	134	41	25	163	94

(a) % IACS at 20 °C (68 °F). (b) At 20 °C (68 °F). (c) At 25 °C (77 °F). (d) Per circular mil/ft. (e) All H1x-type tempers.

trol of metal flow places a few limitations on the design features of the cross section of an extruded shape that affect production rate, dimensional and surface quality, and costs. Extrusions are classified by shape complexity from an extrusion-production viewpoint into solid, hollow and semihollow shapes. Each hollow shape—a shape with any part of its cross section completely enclosing a void—is further classified by increasing complexity as follows:

- Class 1—A hollow shape with a round void 25 mm (1 in.) or more in diameter and with its weight equally distributed on opposite sides of two or more equally spaced axes
- Class 2—Any hollow shape other than Class 1, not exceeding a 125-mm-diam (5-in.-diam) circle and having a single void of not less than 9.5 mm (0.375 in.) diam or 70 mm^2 (0.110 $in.^2$) area
- Class 3—Any hollow shape other than Class 1 or 2

A semihollow shape is a shape with any part of its cross section partly enclosing a void having the following ratios for the area of the void to the square of the width of the gap leading to the void:

Gap width mm	in.	Ratio
0.9 to 1.5	0.035 to 0.061	Over 2
1.6 to 3.1	0.062 to 0.124	Over 3
3.2 to 6.3	0.125 to 0.249	Over 4
6.4 to 12.6	0.250 to 0.499	Over 5
12.7 and greater	0.500 and greater	Over 6

Alloy Extrudability. Aluminum alloys differ in inherent extrudability. Alloy selection is important, because it establishes the minimum thickness for a shape and has a basic effect on extrusion cost. In general, the higher the alloy content and the strength of an alloy, the more difficult it is to extrude and the lower its extrusion rate.

The relative extrudabilities, as measured by extrusion rate, for several of the more important commercial extrusion alloys are given below.

Alloy	Extrudability, % of rate for 6063
1350	160
1060	135
1100	135
3003	120
6063	100
6061	60
2011	35
5086	25
2014	20
5083	20
2024	15
7075	9
7178	8

Actual extrusion rate depends on pressure, temperature and other require-

Table 5 (continued)

Alloy	Temper	Tensile strength MPa	ksi	Yield strength MPa	ksi	Elongation(a), % (b)	(c)	Hardness(d)	Shear strength MPa	ksi	Fatigue strength(e) MPa	ksi
5254	H32	270	39	205	30	15	...	67	150	22	125	18
	H34	290	42	230	33	13	...	73	165	24	130	19
	H36	310	45	250	36	12	...	78	180	26	140	20
	H38	330	48	270	39	10	...	80	195	28	145	21
	H112	240	35	115	17	25	...	63	...	...	115	17
5454	O	250	36	115	17	22	...	62	160	23	...	...
	H32	275	40	205	30	10	...	73	165	24	...	...
	H34	305	44	240	35	10	...	81	180	26	...	...
	H36	340	49	275	40	8	...	...	...	...	...	...
	H38	370	54	310	45	8	...	...	...	...	...	...
	H111	260	38	180	26	14	...	70	160	23	...	...
	H112	250	36	125	18	18	...	62	160	23	...	...
	H311	260	38	180	26	18	...	70	160	23	...	...
5456	O	310	45	160	23	...	24	...	...	...	...	...
	H111	325	47	230	33	...	18	...	...	...	...	...
	H112	310	45	165	24	...	22	...	...	...	...	...
	H321, H116	350	51	255	27	...	16	90	205	30	...	...
5457	O	130	19	48	7	22	...	32	83	12	...	...
	H25	180	26	160	23	12	...	48	110	16	...	...
	H28, H38	205	30	185	27	6	...	55	125	18	...	...
5652	O	195	28	90	13	25	30	47	125	18	110	16
	H32	230	33	195	28	12	18	60	140	20	115	17
	H34	260	38	215	31	10	14	68	145	21	125	18
	H36	275	40	240	35	8	10	73	160	23	130	19
	H38	290	42	255	34	7	8	77	165	24	140	20
5657	H25	160	23	140	20	12	...	40	97	14	...	...
	H28, H38	195	28	165	24	7	...	50	105	15	...	...
6005	T1	170	25	105	15	16	...	...	...	...	97	14
	T5	260	38	240	35	8	10	95	205	30	97	14
6009	T4	235	34	130	19	24	...	70(p)	150	22	115	17
	T6	345	50	325	47	12	...	...	...	...	...	...
6010	T4	255	37	170	25	24	...	76(p)	...	...	115	17
6061	O	125	18	55	8	25	30	30	83	12	62	9
	T4, T451	240	35	145	21	22	25	65	165	24	97	14
	T6, T651	310	45	275	40	12	17	95	205	30	97	14
Alclad 6061	O	115	17	48	7	25	...	...	76	11	...	...
	T4, T451	230	33	130	19	22	...	...	150	22	...	...
	T6, T651	290	42	255	37	12	...	...	185	27	...	...
6063	O	90	13	48	7	...	...	25	69	10	55	8
	T1	150	22	90	13	20	...	42	97	14	62	9
	T4	170	25	90	13	22	...	...	...	...	...	...
	T5	185	27	145	21	12	...	60	115	17	69	10
	T6	240	35	215	31	12	...	73	150	22	69	10
	T83	255	37	240	35	9	...	82	150	22	...	...
	T831	205	30	185	27	10	...	70	125	18	...	...
	T832	290	42	270	39	12	...	95	185	27	...	...
6066	O	150	22	83	12	...	18	43	97	14	...	...
	T4, T451	360	52	205	30	...	18	90	200	29	...	...
	T6, T651	395	57	360	52	...	12	120	235	34	110	16
6070	O	145	21	69	10	20	...	35	97	14	62	9
	T4	315	46	170	25	20	...	90	205	30	90	13
	T6	380	55	350	51	10	...	120	235	34	97	14
6101	H111	97	14	76	11	...	...	...	...	...	...	...
6151	T6	220	32	195	28	15(q)	...	71	140	20	...	...
6201	T6	330	48	300	43	17	...	90	...	...	...	...
	T81	330	48	310	45	6(f)	...	...	...	...	...	...
6205	T1	260	38	140	20	19	...	65	...	...	...	...
	T5	310	45	290	42	11	...	95	205	30	105	15
6262	T9	400	58	380	55	...	10	120	240	35	90	13

(continued)

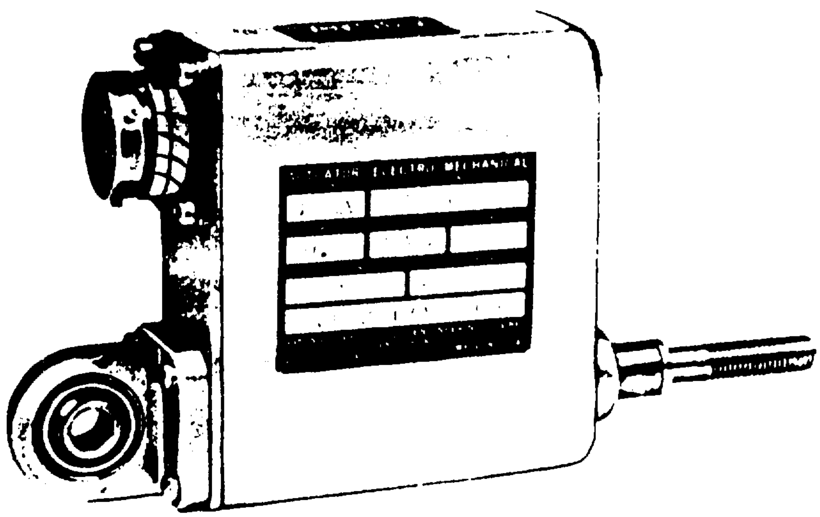
APPENDIX D
ACTUATOR INFORMATION

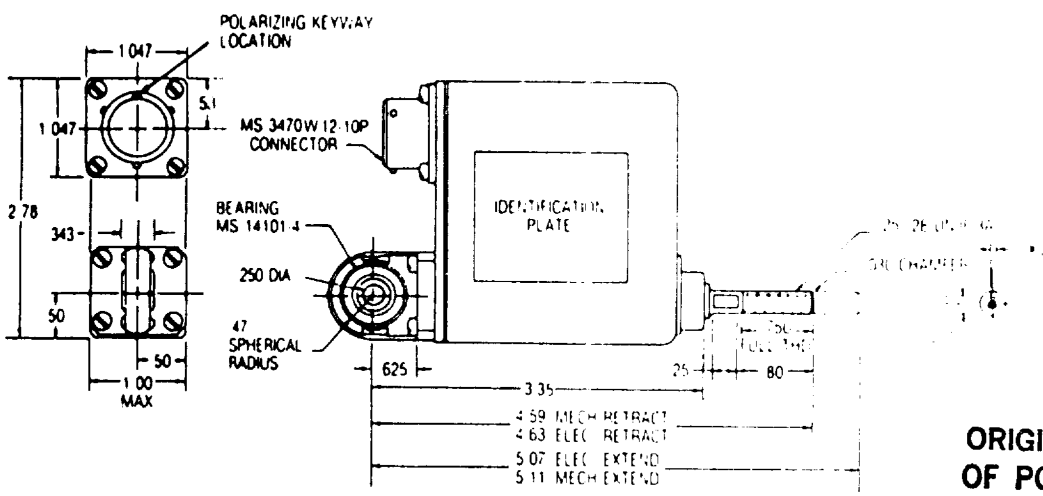
MLD 1000-20
Miniature DC Linear Actuator

This small electromechanical actuator was designed for use on a Military Helicopter to operate the Tail Wheel locking mechanism. The actuator meets all applicable specifications of the U.S. Army and U.S. Navy.

Electromagnetic interference is suppressed by an integral EMI Filter and switch transients are attenuated by additional circuitry. The unit contains stroke limit and indicator switches. To obtain a precise electrical stroke the actuator motor is dynamically braked at the limits.

While the nominal load rating of this actuator is 30 pounds, the unit is capable of operating against loads up to 180 pounds without affecting life or reliability. A wide range of speed/load variations are available for applications requiring light weight, high reliability and small envelope. Various options in wiring and motor selection are available, as well as variations of fixed end and rod end fittings.





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SPECIFICATIONS

TYPE	Electromechanical Linear
RATED LOAD	30 lbs. (14 Kg)
MAXIMUM OPERATING LOAD	180 lbs. (82 Kg)
MAXIMUM STATIC LOAD	200 lbs. (91 Kg)
ULTIMATE STATIC LOAD	300 lbs. (136 Kg)
ELECTRICAL STROKE	.44 inch (11,2 mm)
RAM STOPS	Electrical limit switches & non-jamming positive stops
RAM ANTI-ROTATION	Equipped with anti-rotation device.
LIFE AT RATED LOAD	5,000 cycles (minimum)
DUTY CYCLE	Intermittent
OPERATING VOLTAGE	28 volts DC (range 18-30 volts DC)
MOTOR TYPE	Permanent magnet
BRAKE TYPE	Dynamic Braking at electrical stops
TEMPERATURE RANGE	−65°F to +160°F (−54°C to +71°C)
LUBRICATION	Lubricated for life
ENCLOSURE	Explosion proof
WEIGHT	.51 lb (0,23 Kg)
QUALIFICATION	MIL-A-8064, MIL-STD-461, MIL-STD-462, MIL-A-85046(AS)

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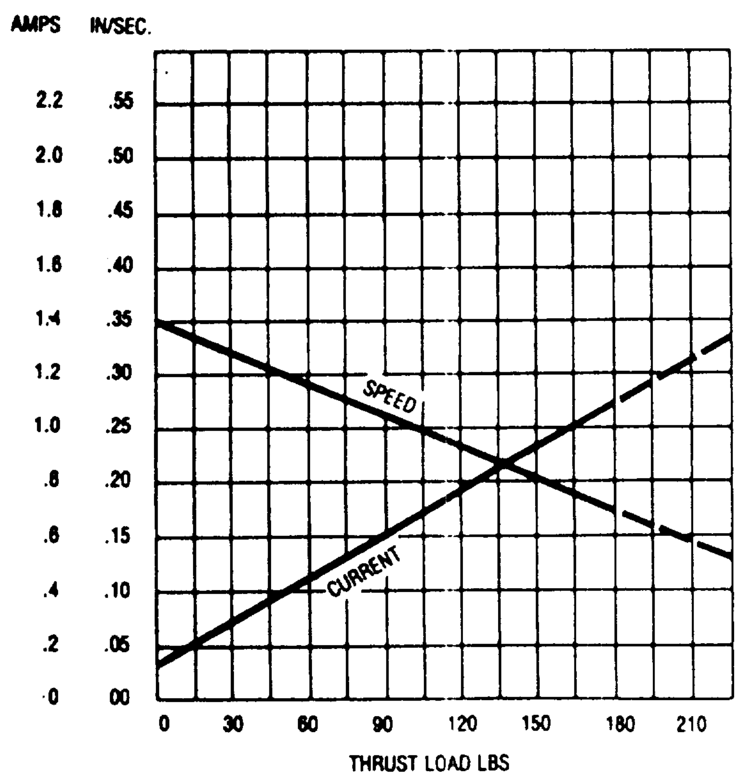
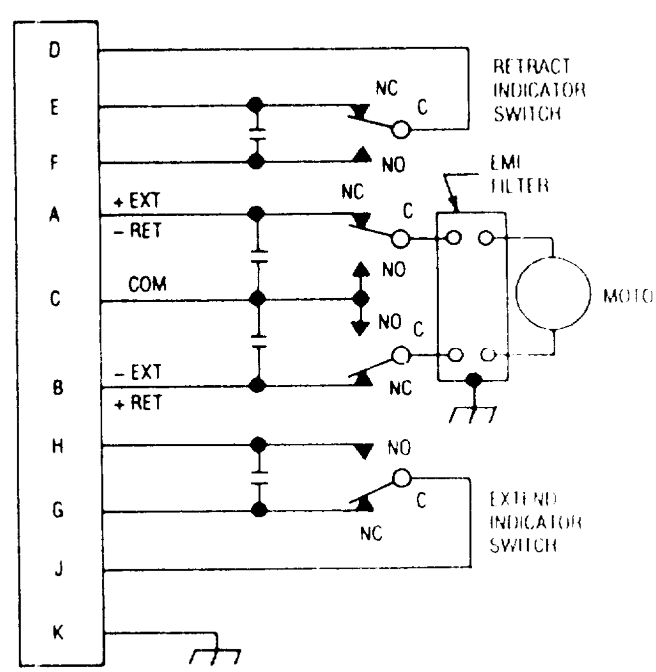
PERFORMANCE CURVE



WIRING SCHEMATIC



UNIT IN MID-STROKE POSITION

APPENDIX E1
WEIGHTS TABLE.

TABLE E1

SKITTER/IMPLEMENT INTERFACE
ME 4182 SPRING '88
LATCH COMPONENT WEIGHTS TABLE

PART	QUAN	VOL (in^3)	WEIGHT (lbm/ea)	TOTAL (lbm)
Cams	2	1.398	0.1370	0.2740
Camshafts	2	1.546	0.1515	0.3030
Roller Mounts	4	0.105	0.0103	0.0412
Roller Shafts	2	0.054	0.0053	0.0106
Rollers	2	0.196	0.0144	0.0288
Locking Pin	1	1.208	0.1183	0.1183
Actuator	1	-	2.0000	2.0000
Springs	2	-	0.0500	0.1000
Spring Sleeves	2	-	0.0250	0.0500
Front Housing Pl.	1	3.001	0.2941	0.2941
Middle Housing Pl.	1	3.045	0.2984	0.2984
Back Housing Pl.	1	1.269	0.1243	0.1243
Side Housing Pls.	2	0.677	0.0663	0.1326
Bottom Housing Pl.	1	0.492	0.0482	0.0482
Braces	2	0.170	0.0108	0.0216
Spanners	2	0.110	0.0108	0.0216
Foot Rod	1	3.534	0.3464	0.3464
Lateral Foot Brace	2	8.171	0.8008	1.6016
Parallel Foot Brace	2	1.025	0.1005	0.2010
Total per Interface				6.0157
Total for all Interfaces				18.0471

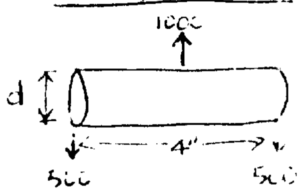
APPENDIX E2
CALCULATIONS.

APPENDIX SECTION E

The forces assumed in this section are somewhat arbitrary, since exact numbers are not as yet determined with regard to the skitter project. A static weight of 500 lb is used for implement weight and 1000 lb total is used to include inertial forces and shock.

A Yield Strength of 35×10^3 psi is used throughout the analysis since all parts are made of Al 6061-T6 unless otherwise noted. This value is typical for the expected moon temperatures. See Figure E1. Also $\tau_{max} = S_{sy} = \frac{1}{2} S_y$

FOOT - rod



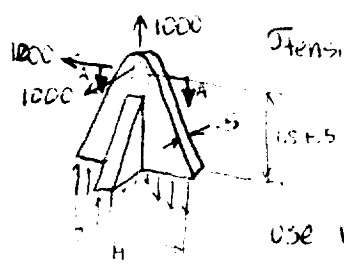
$$\sigma_{max} = \frac{Mc}{I} = \frac{500(2)d\,64}{2\,\pi d^4} = \frac{32000}{\pi d^3}$$

$$d = \sqrt[3]{\frac{32000}{\pi S_y}} = \underline{.663}$$

$$\tau_{max} = \frac{V}{A} = \frac{500(4)}{\pi d^2}, \quad d = \sqrt{\frac{2000}{\pi \frac{1}{2} S_y}} = .191$$

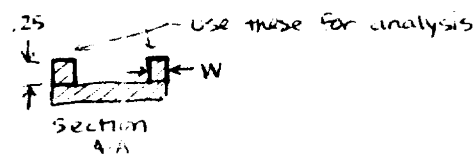
use $d = .75$ which gives max stress of 24144 psi and F.S = 1.45 → used $d = 1$, $\sigma_{max} = 10186$, FS = 3.4

FOOT - supports



$$\sigma_{tensile} = \frac{1000}{A} = \frac{1000}{2(.25)w}$$

$w = .057$

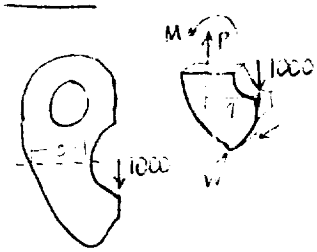


use $w = .125$ ∴ $\sigma_{tensile} = 16000$ psi F.S = 2.19

$$\sigma_{bending\,max} = \frac{Mc}{I} = \frac{1200(1.8+.5)H\,12}{2(.5)H^3} = \frac{33120}{H^2} \qquad H = .973$$

use 30° angle at base. F.S = 3

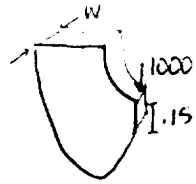
CAMS determine width



$$\sigma = \frac{1000(.5)12}{.8^3\,w} + \frac{1000}{.8w}$$

use $w = .75$

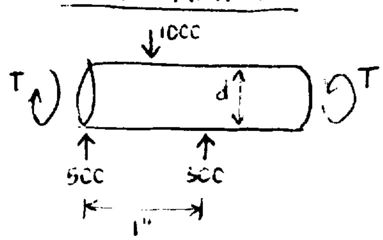
$\sigma_{max} = 29791$, FS = 1.175



$\tau = \frac{V}{A} = \frac{V}{dw} = \frac{1000}{.15w}$, $w = \frac{1000}{.15\frac{1}{2}S_y} = .38$

for $w = .75$, $\tau = 8889$ & F.S = 1.97

CAMSHAFTS



worst case on cam causes 1000 in·lb of torque that the shaft must support.

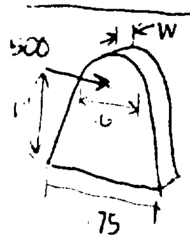
$\tau_{max} = \frac{Tr}{J} = \frac{1000\,d\,32}{2\pi d^4} = \frac{16000}{\pi d^3}$ $\quad d = \underline{.663}$

$\sigma_{max} = \frac{Mc}{I} = \frac{500(.5)d\,64}{2\pi d^4} = \frac{8000}{\pi d^3}$ $\quad d = .417$

$\tau_{shear} = V/A = \frac{500(4)}{\pi d^2}$ $\quad d = .19$

use $d = .75$ then max stress = 12072, F.S = 1.45

ROLLER MOUNTS



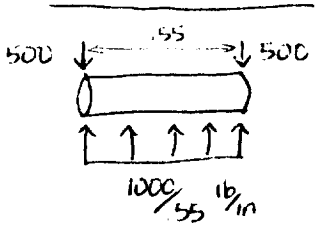
$\sigma = \frac{Mc}{I} = \frac{500(1)(.75)\,12}{2(.75)^3\,w} = \frac{5333}{w}$ $\quad \underline{w = .1524}$

$\tau = V/A = \frac{500}{.6w}$ $\quad w = .0476$

use $w = .25$ $\sigma = 21332$, FS = 1.64

(force is 500 because moment arm is 1" and there are two mounts per side)

ROLLER SHAFT



the roller exerts a distributed load on the shaft.

$\sigma_{max} = \frac{Mc}{I} = \underbrace{\left(-\frac{1}{12}1818(.55)^2\right)}_{M_{max}} \underbrace{\frac{d}{2}}_{c} \underbrace{\frac{64}{\pi d^4}}_{1/I}$ $\quad d = \underline{.237}$

$\tau_{max} = \frac{V}{A} = \frac{500(4)}{\pi d^2}$ $\quad d = .191$

use $d = .25$, $\sigma_{max} = 29876$, FS = 1.17

HORIZONTAL LOADS

Low horizontal loading is assumed because skitter has a tendency to slide across the lunar surface. A skitter/dust coefficient of friction of .5 was used in analysis

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